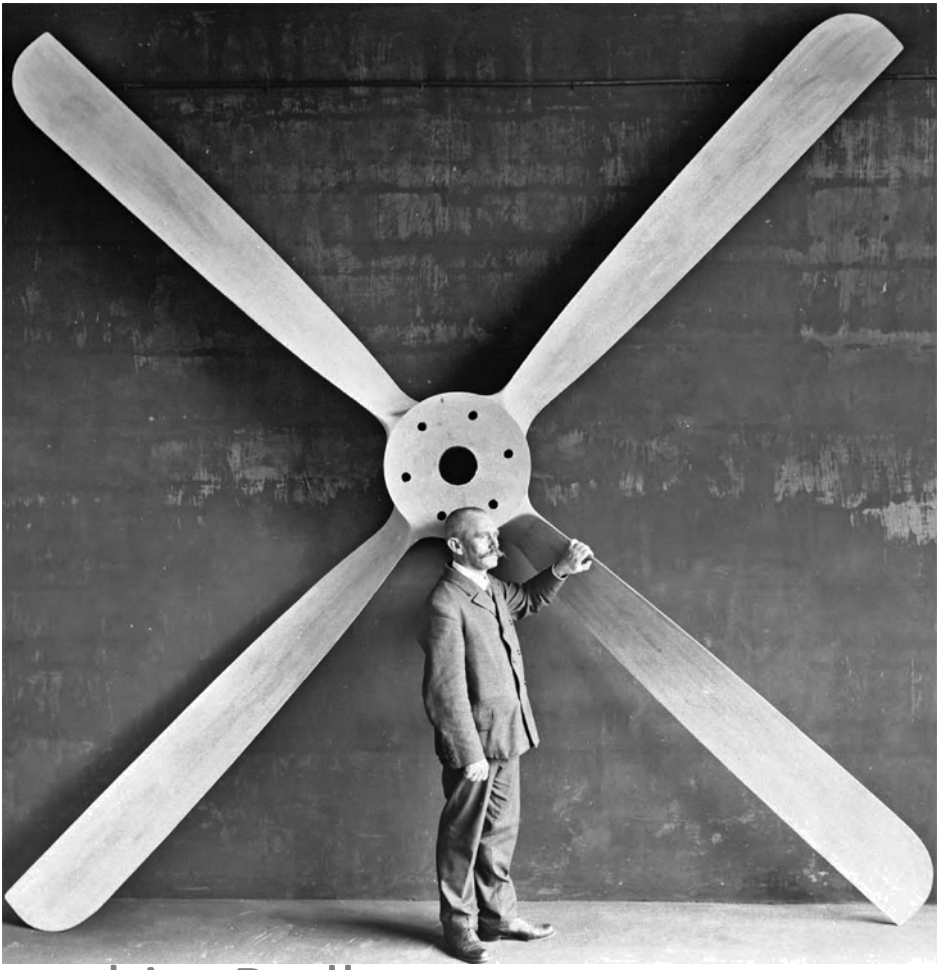

Joachim Radkau

TECH INK DEUTSCHLAND

From the 18th century to today

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Joachim Radkau is Professor of Modern History, in particular the history of technology, at Bielefeld University. He is one of the most renowned German historians of technology and the environment. His book "Technology in Germany" was first published by Suhrkamp in 1989 and is now available in a comprehensively revised and updated new edition.

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Joachim Radkau

Technology in Germany

From the 18th century to today

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Introduction

1. Rethinking technology - Apology of the history of technology

Does it make sense to write the history of technology as a national history? Isn't technology essentially supranational and based on natural laws, and doesn't the growing global interdependence mean that things are becoming more and more similar all over the world? Certainly, but this is not the only history of technology, there is another one: a history of adapting technology to different national and regional conditions. But this other history has only just begun to be written, because unlike the linear, abstract history of progress - this history of progress towards greater power, greater speed, more perfect networking - it requires much more attention to detail: to materials and material testing, to dimensioning and design, to the precision of work and the qualifications of workers, to dealing with risks and consumer preferences.

But only this other history of technology can be connected to the "main streams" of historical research. And it is precisely this very concrete history of technology, which tracks down the "devil in the detail" and sees the machines together with living people, that gives us a great deal, an infinite amount to think about and ponder. It offers the best opportunity for a critical historical analysis that examines how technology interacts with power, with human needs, with environmental conditions. If this book is about the history of technology in Germany, it is also about the position of technology in German history since the 18th century. A first version of this book was suggested by Hans-Ulrich Wehler over 20 years ago. My ambition then was to give the history of technology - which, as a pure history of progress, was a foreign body in modern historiography - its place in the critical historical revision of the Bielefeld School. For this reason, the role of the state in technological development also receives special attention.

Well, that's an old story. It has its stories. For example this one: Friedrich August Eversmann, royal Prussian factory commissioner, in his tireless zeal for innovation felt, by his own admission

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"always like a hunted stag": he was already the type of high-pressure nerve agent who only became the German prototype a hundred years later. When, in 1788, he pressed the reluctant Prussian king all too insistently to promote labor-saving machines, the head of the mining and war department, Baron von Heynitz, silenced him by tugging on his skirt. Heynitz knew the courtly customs, and he also had experience with technical innovations.

In the past, it was considered a natural duty of honor for the historian of technology to inspire new generations with a story of the triumph of technical progress and of ingenious inventors. Those days are a thing of the past, and this type of literature survives mainly in glossy books in station bookshops. Instead, there is reason to ask whether the historian of technology - always assuming that science has something to do with wisdom - would not be better suited to the other role: the role of someone who tugs hard on the jackets of those lobbyists who are lobbying politicians to subsidize certain supposed "future technologies".

Figure 1: Election poster in Mecklenburg, 1998, suggesting a technicist model of progress to the new federal states that many citizens of the old federal states already consider passé: technical innovation per se, regardless of whether there is any need for it and regardless of how absurd it may be, is presented as a miracle cure for job creation. The poster assumes that the promotion of such innovations is the task of the state.

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At the Munich SPD party conference in 1956, Leo Brandt, the Social Democratic thought leader on technology at the time, assured the party members of what an American company representative had told him - and there is no contradiction in the minutes: a nuclear power plant that would supply an entire city with electricity would only cost one million dollars, would be maintenance-free and would fit in a box; you would simply have to bury it in the ground, "half a meter of gravel over it, and a cable would come out at the end".

Since that time, a popular technological "Germany awake!" literature has been sprouting new flowers. The tenor is always stereotypically the same, as if we were still in the Biedermeier era: the Germans in their coziness are once again about to oversleep the global race of technical innovations; they should take an example from the Americans (later: the Japanese, today: the Chinese). At the end, usually explicitly or between the lines, the punch line: politicians and the public must finally learn that a certain industrial sector (with which the author is often somehow connected) needs a lot of taxpayers' money. The label "research" is often used to justify subsidies. And this is done in a sonorous tone of conviction that makes any doubts appear ignorant or petty. As these are usually publications with a short-term effect that are soon sold off, their blatantly false predictions (headline in 1959: "Nuclear battle" over the high-temperature reactor!) are quickly forgotten: the gap in the market for this literature opens up again and again.

This genre of literature needs its own kind of textual criticism and critical Remembrance. Previous research into the history of technology usually gets stuck on the threshold of the present; but it is precisely the very latest era, for which a popular literature that is untainted by any criticism of knowledge and at the same time deals with politically explosive issues has predominated up to now, that is in particular need of a professional, source-critical approach to the history of technology. Today, there is a widespread belief that the triumph of the computer demonstrates the irresistibility of technical innovation per se. But beware: the success of innovations has unique historical characteristics throughout; deriving general "innovation theories" from this, which offer more than banalities, is misleading. Rather, we can learn from the history of technology that innovations are usually economic flops - Reinhold Bauer has specialized in "historical flopology" within the history of technology with astounding success. Hence the admonition of the experienced technology historian Akos Paulinyi: A good entrepreneur must not have a technology bug. A memento that has seldom been as topical as in recent times!

But why is this experience always forgotten? Because the culture of remembrance in company anniversary publications prefers to forget failures.

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and because the history of technology predominantly cultivates only the successful innovations in memory. But, to paraphrase Hegel: "The true is the whole" - the failures are also part of the true history of technology. And this is also where the practical benefits of a critical history of technology lie. The great successes are passed on to posterity even without historians.

Der *Spiegel* of December 18, 1989 presented the first version of this book as a technical-historical counterpart to Sten Nadolny's historical bestseller *The Discovery of Slowness*. And, quite rightly, a leitmotif of my presentation was aimed in this direction. Especially in the speed-obsessed history of technology, discovering the benefits of a certain slowness can always provide new aha moments. If the Germans were considered to be a people of leisureliness and leisureliness compared to the English, French and Americans until well into the 19th century, this actually benefited them in many areas of technology where success was only possible through gradual "development". As paradoxical as it sounds, sometimes technologies - such as nuclear technology - become more conservative the more they are pushed. There is a logic to this, because if something is to be implemented quickly on a large scale, engineers have no choice but to fall back on existing know-how and conventional components. In Germany, success in the past was often achieved by taking one's time, while the "speed" that became the hallmark of the
"nervous age", has not a little to do with the German catastrophe.

When I started working on the first version of this book 20 years ago, I made a page-long list of pros and cons as to whether or not I should buy a PC for word processing. I decided to wait and continue writing by hand as usual. I kept bumping into pale PC pioneers in the corridor whose computers had crashed again. These Icaruses and Otto-Lilienthals of new technology were to be honored, but I didn't feel the slightest ambition to join them. Meanwhile, my prominent colleague Niklas Luhmann, the Bielefeld sociology pope, was conjuring up computer theories from his box of notes that were taken seriously even in the scene, but continued to complete his famous boxes of notes himself in hard-to-decipher handwriting.

My uncle Hans Radkau (1904 - 1991), an experienced and universally popular mechanical engineering lecturer at technical universities with memories stretching back to the German Empire, to whom I owe my interest in the history of technology and who always accompanied my work on the history of technology with advice and sympathy, lived by the ancient wisdom of living with such

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SCIRE. DEI MVNVS. DIVINVM EST NOSCERE VELLE.
SED FAS LIMITIBVS SE TENVISSE SVIS
DVM SIBI QVISQ. SAPIT NEC IVSTI EXAMINA CERNIT.
ICARVS ICARVS NOMINA DONAT AQVIS

Figure 2: Crash of Icarus, copperplate engraving by Hendrik Goltzius, 1588. The Latin circular text reads in German translation: "Knowledge is a divine gift, and the thirst for knowledge is divine, but the commandment is not to overstep one's own boundaries. He who thinks only for himself, without subjecting it to a proper examination, gives his name - as an Icarus - to Icarian waters." Since the late Renaissance, in the wake of the rise of technology, the Greek myth of Daedalus and Icarus has become a popular motif in art and literature. Icarus crashed because he flew too high towards the sun, melting the wax that held his wings together. Goltzius, who was the first to deviate from the iconographic tradition of Icarus falling, captured the exact moment when Icarus is still gazing transfigured at the sun but begins to fall. In his longing, he retains greatness and sensual charm, even if he violates the paternal reason of the moderate center! The image is not as unambiguously moralizing as the circular text, but evokes erotic associations. Indeed, since Ovid's *Ars amatoria, there has been* a tradition of understanding Icarus as the immoderate lover and thus the true lover. Flying as an erotic cipher! It was not until the 18th century that attention turned to the technical aspect.

I tried to get by with as little ballast as possible (with the exception of books, of course), and - mindful of meditative silence - didn't even have a telephone at home, let alone television. This way of life rubbed off on me, and I didn't do badly with it. Of course, I've been "online" for a long time now (... and since then I've experienced sudden changes between over-excited work euphoria and mental paralysis that I'd never experienced before). But 20 years ago, PC technology was not fully developed - and whether it is today

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the question remains. To what extent is there such a thing as "maturity"? Apple products are not apples, and the mouse is not a mouse.

And yet: I am suspicious of sweeping cultural pessimists, let alone apocalyptics. When Lewis Mumford (1895 - 1990), in the 1930s the prophet of a human and environmentally friendly "neo-technology", prophesied the downfall of mankind under the power of a murderous "mega-machine" in his old-age depression, this was a negative variant of the linear image of progress, without any awareness of the fact that the course of technology does not follow a single straight "mainstream" - fortunately not. The old sporting superlatives of technical progress *citius, altius, fortius* - faster, higher, stronger - are becoming increasingly distant from the market as they continue to increase. Crumple zones no longer help the driver in even faster cars. The highest concentrations of force are not to be used in civil engineering, but only in nuclear weapons; but thank goodness the atomic bomb is not the paradigm of new technology per se, and neither is the Manhattan Project, from which the first nuclear weapons emerged, the prototype of modern technical development in general. In the history of technology, spectacular technical superlatives do not have anywhere near the significance that sensationalist media attribute to them. Sputnik was one of the biggest pseudo-events in contemporary history; in those years, pizza was undoubtedly an innovation that was incomparably more important for real life and the economy. Making the trivial historically relevant could be one of the attractions of the history of technology.

The tricky thing is that such an extended history of technology goes beyond all

Boundaries. Bold new concepts of history always face the crucial question of whether the historian who wants to write well-founded and readable books can work with them. This presentation, too, can only imperfectly fulfill its own claim. But the history of technology has too often locked itself into an intellectual ghetto; an impetus towards a certain dissolution of boundaries - a specific, not unlimited one - cannot do it any harm at present.

But where is the common thread in all this? Where is the story in this motley hodgepodge? If we refrain from hanging the entire history of technology on the leash of linear progress, it does not have to lose any line, any dynamism. There is no doubt that there has been a continuous increase in technical knowledge and know-how over the last few centuries - but at the same time, usually unnoticed, there have also been processes of forgetting. In my recapitulation of the history of German technology since the 18th century, I have repeatedly registered *cyclical*, if you like, dialectical processes alongside upward curves.

Many cycles only became clear to me as I was writing, without first having a suitable theory - a concept of business cycles in the

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technology - would have had. Excessive testing of *economies of scale*, i.e. increasing profitability through capacity growth, used to be followed by a setback at some point. Phases of mass and cheap production were followed by new opportunities for diversified quality work. Stormy phases of innovation, along with the inevitable disappointments, were regularly followed by a rediscovery of the benefits of tradition - at least certain traditions. The plastics boom was followed by a renaissance of natural materials. The disregard for the experience of practitioners by visionary reformers and protagonists of new theories was inevitably followed sooner or later by a renaissance of experience. The ever new ambition to get rid of humans and their disruptive stubbornness by means of mechanization was followed, even in the age of robots, by the insight that humans are more flexible than all machines - and often even cheaper. These cycles, these dialectical pendulum swings, are not the least of the epochs in the history of technology.

National styles of technological development - especially those that develop a pronounced dynamic - should not be seen as too homogeneous and inherently harmonious: They are characterized not only by continuities, but also by internal tensions from which cyclical movements emerge. In his comparison of German, British, French and American technical cultures (*Künstler und Strichezieher*, Frank- furt/Main 1999), Wolfgang König came to the initially seemingly paradoxical conclusion that
"in no other country have empirical elements been so largely suppressed from the engineering profession and from engineering education" as in Germany, where engineering schools arose from the needs of the state administration, but also that no other country had developed such an extensive and practical technical secondary school system as the German Reich. It was above all thanks to these technical schools that the number of engineers here was apparently much higher than in other industrialized countries. The prototype of German engineering culture was not only Franz Reuleaux (1829 - 1905), who sought to elevate the technical sciences to the status of philosophy through theory, but also Alois Riedler (1850 - 1936) with his "seven-year war" against Reuleaux and the theory-heavy training of mechanical engineers. Note that both drew on American experience, each in their own way. "America" is big, and different people bring very different messages home from the USA: this is often given too little attention in discussions about "Americanization", both in the past and today, whether in technology or culture.

German paths in technology result from signatures of German history. It was clear to me from the outset that these vary and are not the result of an eternal "German essence". While the style of technical history has usually developed in line with early and highly industrialized technology, it was

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the research basis from which I operated, before and after: in the wood-bound and wood-saving techniques of the early modern period and in nuclear technology. These "eccentric" approaches, as it were, had their advantages: they protected me from the outset from overly static notions of what is typically German in technology. Because in both cases there were German paths, but they looked very different. Even today, the old question "What is German?" is asked again and again - since 1945 in a more thoughtful tone than before. Especially in the course of increasing "globalization" - whatever that may be - the question of the German profile in the world economy has taken on a new kind of sharpness. This book was also written with this discussion in mind.

Since the first version, I have distanced myself from the history of technology for many years: with my work on the history of nervousness, the world history of the environment and the biography of Max Weber. But it is precisely from this distance that I have rediscovered the history of technology time and again: the anthropological aspects of technological change, the historical-theoretical implications of perspectives on the history of technology, environmental aspects of technology. In contrast to today's fashionable dematerialization of history, environmental history in particular reminds us of the material side of human affairs! And of technology: a cultural history of the car may be limited to the bodywork - an environmental history of the car penetrates into its technical inner life. Even Max Weber led me back to technology. For him - very much in contrast to many Weberians today - the appeal of the social sciences lay in the intellectual conquest of new realities; and the world of technology was not least among these. "With what passion would he have studied it in order to see through its function for a political style" if he had only known today's technology, asserted Theodor Heuss, who had known Weber well, in 1958 in the introduction to his *Political Writings*. But the more large sections of the public are hypnotized by new technology, the more the social sciences tend to become entrenched in traditional core areas.

In 1798, in the face of the approaching French Revolution,
Friedrich Schleiermacher, the future "church father of the 19th century", wrote his book *On Religion* in Berlin. *Speeches to the educated among their despisers.* Even without academic church father airs, in the maelstrom of the mechanization of our entire lives, I feel the need more and more to give an apology of the history of technology to its intellectual detractors. Akos Paulinyi in particular, who - where necessary - warned against a belief in technology, has recently railed against self-destructive tendencies in the history of technology: against the dissolution of technology into economic, scientific or discursive disciplines.

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history and against the trivialization of technology with reference to the growing service sector and the alleged "dematerialization" of the economy. Similarly, one cannot polemicize strongly enough against the blatant ignorance of technology within modern history, which results far more from inertia than from theory. If you want to talk about modernity, you also have to talk about technology. However, the history of technology itself is not innocent of its marginality. This book is intended to help bring it into the historical mainstream.

The certain longing of the history of technology for self-dissolution is presumably explained by the urge to escape the technology ghetto - or, as one puts it, the no man's land between the "two cultures": the humanities and social sciences on the one hand, and the technical and natural sciences on the other (both, seen from close up, are also deeply fragmented within themselves). The arrogance of the social scientists is all too often matched by the arrogance of the natural and technical scientists, whose specialist literature is incomprehensible to social scientists and whose popular literature is often not exactly conducive to intellectual debate. One need only think of the cyberneticist Karl Steinbuch's *(Falsch programmiert*, 1968) scolding of the "Hinterwelt", i.e. the humanities, which he accuses of being "cathe- der murderers" and which he blames for the Nazi crimes: an incendiary pamphlet that once stirred up a lot of dust in the German public, from the Bonn "federal level" to the Hamburg editorial offices, and was taken surprisingly seriously. At a time when even cyberneticists had completely wrong ideas about the computers of the future, Steinbuch treats society as a computer to be reprogrammed, and he presents the Eastern Bloc, which at the time flattered cyberneticists, as a technological role model. On the other side, some paid back with the same coin and associated technology with death. Again and again, the gulf between the two cultures is widening. Historians of technology are faced with the acrobatic feat of bridging this gap. No wonder that many prefer to cling to one side so as not to fall off.

Today's historian of technology usually moves within a triangle between economic, scientific and environmental history. I too have been navigating this triangle for decades. I wrote the first version of the book 20 years ago under the direct impression of an industrial archaeology excursion to England with the economic historian Sidney Pollard (1925 - 1998). Excursions are a good school in concrete thinking. Industrial archaeology encourages you to understand technology in a very concrete way in the factories, in the world of work, in the regional environment. English impressions lead to the identification of German paths in technology.

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I learned from Pollard that "technology transfer" - a buzzword of the 1980s - is a misleading term: according to Pollard, it is precisely developed industrialized countries with a high level of technical competence that know how to adapt imported technology to their own conditions. The naïve enthusiasm for foreign cutting-edge technology is evidence of incompetence and is characteristic of underdeveloped countries. In this approach, which Thomas P. Hughes had already successfully practiced in the American history of technology, I found a key to the German history of technology as well.

Pollard - like so many British intellectuals of his generation, a communist in his youth and a liberal in his older years - mocked state technology policy on occasion: "What the state does is always wrong." Even when it came to technological developments that had a future, he said, there was a mishap as soon as the state took them into its own hands. Indeed, there is no shortage of examples, from the early Prussian steam engines to the state promotion of microelectronics in the GDR. However, this does not mean that it is up to the historian to advocate a depoliticization of technological development. Rather, history shows that, in the absence of any state or public pressure, industry neglects even simple labor and environmental protection measures. Pollard by no means preached a return to total laissez-faire, especially not in core technology. Although he was the son of Austrian Jews who were murdered in the Holocaust and experienced England as a lifesaver, he appreciated some German regulatory traditions and wrote a polemic against British Thatcherism (*The Wasting of the British Economy,* 1982). I also learned from that.

I also owe a lot to the collaboration with Pollard's successor,
the economic historian Werner Abelshauser. There is a lot of convergence between his research into the "German production regime" in the economy and my reconstruction of German paths in technology, and in this way I have learned a lot about entrepreneurial aspects of the technological-historical processes I have described. Both of us are aware that we are dealing with German traditions that are currently being traded under price: today, at the height of globalization rhetoric, even more so than 20 years ago. Whether viewed from the perspective of technological or corporate history: The "German production regime", as it is still effective today as a tradition, emerged in the late 19th century, based on an experienced skilled workforce, diversified quality production, forms of co-determination within the company, regional
"Clusters" - cooperation between autonomous companies while avoiding high transaction costs - and cartel agreements that enabled a longer-term orientation. All of this has its economic and its technical side, indeed

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often manifests itself most clearly in technology. Even the most modern computer development is driven to a remarkable extent by regional clusters, whether in Silicon Valley or around Paderborn.

Of course, the regional aspect is not everything: adaptations of American methods of standardized mass production were also part of the "German way". From the perspective of some neighboring countries, the Germans were the "Yankees of Europe" even before 1914. And it is precisely this that gives rise to a dialectical tension in German technological and corporate history. Of course, the "German way" was not and did not always remain the same everywhere, and it was by no means always a recipe for success. But often it was not even clearly recognized or appreciated in its conditions for success. NS effusions about the
"German technology" often had little substance: in the völkisch imagination, the German technician was brimming with Faustian drive, while in reality, people sought to emulate Henry Ford. Hitler mocked the praise of German
"Werkmannsarbeit" internally as a "bluff": that's how little the leader of the pseudo workers' party knew about German skilled worker traditions! Today, it is worth rethinking the current value of real, not imaginary, German traditions beyond technical nationalism.

The historian of technology Ulrich Wengenroth has taken the exact opposite position to Abelshauser with his "cage thesis", which he formulated in this exaggerated form in his contribution "Die Flucht in den Käfig" (The escape into the cage) for the conference volume *Wissenschaften und Wissenschafts- politik* (2002) edited by Rüdiger vom Bruch and Brigitte Kaderas and which has been stirring up some dust ever since. If you want to increase the intellectual tension when going through the history of German technology, it is worth keeping an eye on these contrasting positions. Like Abelshauser, Wengenroth recognizes a distinctive and tenacious tradition of German corporate culture for over a hundred years, but, in contrast to Abelshauser, has long seen this as the undoing of the German economy. World wars, self-isolation and National Socialism had led to the German "innovation system" locking itself in a "cage". The decline of German science was accompanied by a decline in the culture of innovation in business and technology, accelerated particularly blatantly by the expulsion of scientists of Jewish origin from Germany after 1933. The end result was tantamount to a "self-defeat of the German innovation system".

I owe Wengenroth important suggestions for the reconstruction of German
of the negative view neither logically nor historically and empirically, nor is it able to recognize its analytical value. German history in the
20th century to that night when all cats are gray; even the federal

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The German Gründerzeit is merely an appendix to the German catastrophe, not a promising new beginning. Even the comparatively low share of the service sector in Germany to this day is attributed to German self-segregation. At the bottom, one recognizes the already contradictory premises that the well-being of a country depends on its "innovation system", that this is an integral part of its entire intellectual culture, and that salvation lies in a permanently growing service sector.

The real story looks very different. The expulsion of the German-Jewish intelligentsia has made German culture and science poorer, but has had little recognizable influence on the course of events in industry and technology. The economy and technology can flourish while culture and parts of science lie dormant; there is no close and direct causality: recent German history has shown this. The historian George W. F. Hallgarten (1901-1975), who emigrated in 1933 - a pioneer in the economic interpretation of history with whom I worked in my younger years - used to emphasize, not without melancholy, that in *one* case in particular, German emigrants as a group had initiated a technical innovation of world-historical significance: the construction of the first atomic bomb. The importance of physical theory was far greater there than in the production of consumer goods. But the *Manhattan Project* - fortunately - did not become a paradigm for German industrial research.

I can find many counterexamples to Wengenroth's thesis that the "German innovation system" is "all the more competitive the more distant it can act from consumers" in the history of German technology. Although there is no shortage of mega-projects that are driven forward with technical fanaticism and a productivism that doesn't give a damn about consumer preferences, these are by no means always typically German phenomena. The Ford system was the archetype of productivism par excellence in the 20th century, just as the *Manhattan Project was* the archetype of the megaproject. I, too, consider such trends in German technological history to be fatal; indeed, this is one of the main lines of this book. However, these dark sides of the history of technology do not prove the existence of a German cage.

Certainly, on an ideological level, many Germans have locked themselves in a cage for generations; on a technological level, however, I cannot detect much of a cage psychosis. Instead, the entire history of German technology since the time of Friedrich List can be described as a succession of adaptations of American trends: This is also what this book seeks to show. Even Hitler had no prejudices against the USA when it came to technology and organization; quite the opposite. It is true that, if you look closely, the "Americanization" of the German economy only took place with a few exceptions. But these modifications, the German

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In many cases, the methods used by the German economy to meet the requirements of the American situation are evidence of competence, not nationalistic narrow-mindedness. On the other hand, the German economy typically came to grief when it overzealously adopted American methods of standardized mass production, whether during the global economic crisis around 1930 or the crisis of Fordism in the early 1970s. The crash of the *New Economy* in 2001 also indicates that a
"cage" of fixed ideas has long been more of a blind imitation of American trends than a return to German expertise. How far this will continue to apply in the future - who wants to know?

The combination of technological and economic history is particularly solid. However, I also learned a lot from collaborating with science researchers: with the Bielefeld Institute for Science and Technology Research (IWT), with Wolfgang Krohn and Peter Weingart; also by working on a project on large technical systems by Ingo Braun and Bernward Joerges at the Berlin Social Science Center (WZB), where the intrinsic weight of things, of technical artifacts and networks, came more to the fore. Perhaps it's a good thing that I never had an institute for the history of technology: I always had to be careful about connectivity, not least with an extremely self-confident history faculty that had no innate relationship to technology and first had to be convinced of the benefits of the history of technology. And so, for me, the identity of the history of technology never emerged by itself: through a glass door that would have separated my institute from the rest of the world. Instead, I often saw the history of technology from the outside through my other projects.

But it is precisely because of this that I come to the conclusion that the history of technology could confidently defend its own rights more aggressively. In the triangle of economic, scientific and environmental history, it should move with autonomous elegance in the three-step waltz and not allow itself to be embraced by one of these disciplines. Certainly, in the endless stream of history, technology is not the final cause. But it does produce a lot of rapids, weirs, canals, edgings and slides in this stream, which colossally accelerate the speed of flow.

If, for example, the entire history of technology were to be dissolved into economic history, this would make the course of technology far too rational. The market alone is not enough to explain technical developments. These often need a lot of staying power; as a mere reaction to the eternal balance between supply and demand, they do not come to fruition. Hence the constant call for state subsidies for supposed "future technologies"!

Modern technology cannot be explained - as was sometimes attempted in the past - as the reinforcement and substitution of human organs, nor can it be

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not simply as a response to human needs. It is questionable whether mankind before Gottlieb Daimler had been vegetating for centuries with an unsatisfied need for the automobile. The rapidly growing importance of advertising since 1900, which was particularly excessive in the marketing of new technical consumer goods, indicates that new industries, in contrast to the early industrial textile and mechanical engineering industries, did not simply satisfy an existing need more cheaply and more abundantly, but had to create their own needs first. This can even be seen as a basic trend in the mechanization of economic life; this is one of the leitmotifs of this book. Another trend is the growing pull emanating from the expansion of armaments and armaments research: This brings into play a non-market driving force on a scale hardly known until the 19th century. Not to mention the increasing importance of technical infrastructures and comprehensive technical systems! These have always been a political issue; and this is where the development of technology most obviously has a regional impact.

History of technology and history of science: For some time now, *scientificization* has been considered a promising paradigm in the history of technology and technology policy - not least because the history of science is better established in the scientific community than the history of technology, more easily attains an intellectual level and "science" more clearly signals a claim to state funding than "technology". The offspring of the history of technology sometimes seeks refuge in the history of science. And yet the warnings of die-hard historians of technology against the appropriation of the history of technology by the history of science are still relevant, even in the case of "new technologies". It is very doubtful whether the often claimed law that the path from "research and development" (which is by no means always a smooth transition!) to industry is becoming ever more direct and shorter actually exists. Prime examples where this was the case become an optical illusion if they are hastily generalized.

Since the Geneva Nuclear Conference in 1955, when the fusion reactor, so fascinating in theory, was promised in 20 years, the road to it has not become any shorter, but rather longer. A characteristic learning process in the course of nuclear technology development has been that mere "paper reactors", which may be theoretically optimal, are worth nothing if they are not based on a broad pool of experience in power plant construction. The large nuclear research centers, which were considered by both supporters and opponents of nuclear power to be the masterminds of nuclear development, were in the end astonishingly insignificant for the actual course of events, even leading the development into dead ends. Even today's computer world is neither a direct descendant of the old calculating machines nor of the semiconductor.

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research; nor did it spring directly from research projects. In general, it does not look as if trial and error, the age-old method of technical "development", has been completely supplanted by theory. Even in technology, "development" retains an element of aimless *evolution* and does not consist solely of purposeful *development*. In short: the history of technology is history in the full sense, not merely the unfolding of technical logic.

When exploring German paths in technology, the relationship to science is of particular importance and therefore a leitmotif of this book, as the scientification of technology was long regarded as a typically German (later also American and Soviet) path. From the early 19th to the early 20th century, progress through the scientification of technology was virtually a German ideology. But "science" is an ambiguous term whose content has changed over the course of the history of science. You always have to look closely at what is actually meant by "scientification". A one-sided theory-based development of technology regularly collides with the power of experience at some point: such wave movements can be discovered in the German history of technology in particular. The history of technology in the GDR in particular offers a lesson in overestimating the practical value of state-institutionalized science for technology, based on a far too one-sided understanding of German technological history.

There is a fundamental contradiction between science and technology in the interest of knowledge: The law of science is the pursuit of knowledge, the law of technology is the development of usable artifacts. And yet, that is not all. Utilitarian interests have often promoted scientific creativity - certainly more often than the lobbyists of basic research admit. Martin Heidegger reminded us (although he didn't like it) that modern technology is historically ahead of modern science. Incidentally, "science" should not only be understood as that which is practiced at universities. The spirit of methodically exact and systematic experimental research is also at work in industrial laboratories; not only technology but also science owes important impulses to these.

Probably the most influential new trend of the last two decades, both in the history of technology and in the social sciences in general, is *constructivism*: technology neither as the spawn of a technical logic nor an economic calculation, but as a social construct that - originating from word figures - first took shape in linguistic formations before it materialized. For historians of technology, this new "turn" has the strategic advantage of bringing them out of the intellectual ghetto and into the social science "mainstream".

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and also promises to make their story more intellectual. Technical solutions - according to the premise - arise in communicative processes and are negotiated between the participants.

There is no doubt that this premise is productive for research as a working hypothesis. In a certain sense, it even leads the history of technology to self-awareness; for it has always preferred to rely on words rather than on silent things, but has by no means always dealt with its texts in a source-critical manner and often had no eye for the peculiarity of the word figures. When in the salt works of the 18th When in the salt works of the 18th century, which were not yet spas but salt pro- ducers, the construction of graduation towers was justified with the "so terribly invasive lack of wood" - the salt content of the brine was enriched by the dripping from the graduation towers and in this way fuel was saved in the boiling process - you first have to understand that this alarm was a topos of the time: This realization once gave me an aha moment and became the starting point for a new revisional approach to the history of wood as a factor in pre- and early industrial technology.

David Gugerli's *Redeströmen* (1996), the genesis of Swiss electrification, is a particularly exemplary constructivist history of technology on a grand scale. His topic was ideal for this, as early electrification was a verbose process with lots of suggestive advertising and visionary exhibitions. Later, Switzerland with its Alpine water power seemed predestined by nature for "power current"; in reality, however, it was not only the waterfalls but also the cascades of words that led to this. In Germany, too, electrification offers a prime example of how the implementation of a new large-scale technical system - the technical "network" par excellence - does not follow a purely technical logic, but is driven forward by plans for the future that also promise to solve social problems. The first major
"Power stations" around 1900, which were not merely used to supply electricity to the streetcars, first had to create a network of customers that would make them profitable; they were by no means responding to an existing demand. While technicians with their proverbial "papyrophobia" were usually taciturn, the type of eloquent electrical prophet now appeared on the scene, whether Walther Rathenau in Berlin or Oskar von Miller in Munich.

However, technical "discourses" of this kind are by no means to be confused with "communication free of domination" à la Habermas! Nor are they identical with "discourse" à la Foucault, which has no subject but is driven forward by the generative power of word figures. The "power centers" were about money and power from the very beginning. High chances of winning stood

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Figure 3*:* The art of the penny-farthing rider and constructivism put to the test: the photo reveals the acrobatic skill that the penny-farthing rider needed to get onto the man-sized bike and stay upright. As long as the bike had no chain transmission, the pedal bike had to get higher and higher the faster you wanted to cycle; and the higher it was, the better it absorbed the shocks, as long as it had no pneumatic tires. But the penny-farthing rider had to be as cold-blooded as a stuntman and as agile as a rubber man: it was said that he suffered several head crashes on every tour. Constructivists explain the penny-farthing era by saying that the cyclists of the time designed their penny-farthing bikes in their heads: they were daredevil athletes who wanted to attract attention and look down on their fellow human beings. Therefore, they did not accept the pitfalls of the penny-farthing as a problem to be solved (Wiebe E. Bijker et al. ed., *The Social Construction of Technological Systems,* Cambridge, Mass. 1987). However, when the low-wheeler arrived around 1890, it became established in no time at all, and within a short period of time the penny-farthing disappeared from the streets, although typical cyclists were still sports fanatics. There is a lot to be said for the technical and physical explanation: pneumatic tires and chain transmission made the low wheel possible; it is much safer and more comfortable than the high wheel, and falls from a height hurt, regardless of the socio-cultural context.

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The initial risks of loss were considerable. Regional supply monopolies minimized these risks. In the title of Thomas Hughes' pioneering work on the electrification of Berlin, London and Chicago: *Networks of Power* (1983), "power" is to be understood in two senses: as electrical energy, but also as power. The power plants and their networks are among the largest industrial power complexes of the 20th century. Before the nuclear conflict brought them into the public spotlight, they loved to remain inconspicuous, even developing a pronounced aversion to publicity. The historian of discourse, who does not delight in the mere ringing of words but wants to touch the nerve of power in the spirit of Foucault, must become a detective. The arcana of the energy industry cannot be accessed via the published "discourses" alone. You could be forgiven for thinking that we have long been living in the era of renewable energies!

A classic example of what the history of discourse can achieve and where it can lead us astray is the history of nuclear energy, which was once my introduction to the history of technology. At first, I wanted to structure my habilitation thesis on the *rise and crisis of the German nuclear industry* (1983) according to the four nuclear programs, similar to my predecessors. It was only after studying the files and talking to former participants that I realized that these programs were just paper: Mandatory exercises for parliament and the Ministry of Finance, while real development followed different rules. I then divided the history of nuclear energy into two major periods of a completely different kind: the "speculative phase" and the era of creating finalized facts. It became clear to me that the decisive turning point came at the moment when nuclear energy no longer existed only in words, programs and projections, but on a massive real scale in large-scale power plants that set in motion the "normative power of the factual" and the pull of the billions invested.

With the "atomic age" euphoria of the 1950s, it is indeed important to realize - and many contemporaries failed to grasp this - that the "peaceful atom" was an empty phrase, not a reality. At that time, there was not even a halfway profitable civilian nuclear power plant anywhere in the world. The nuclear energy that took on verbal form in the discourse of those years was cheap, inexhaustible, environmentally friendly, a counter-world to nuclear bomb technology and could be miniaturized to such an extent that even poor and sparsely populated regions of the Third World finally had their ideal source of energy. However, the crucial point is that this discourse construct "nuclear energy" was not the real nuclear energy. This became apparent in the era of the perfect facts.

In contrast to detached seminar discourses on "reflexive modernization", technology discourses, especially when they have a practical effect, sooner or later come up against the inherent power of things: against reality

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of reality. The opponents of nuclear power in the seventies needed to do nothing more than turn the former "atomic age" ideals against the nuclear technology that actually existed. The greatest anger often arises from disappointed love: the bitter protests of the seventies reflected the disappointed hopes of the fifties, particularly blatantly in the figure of Robert Jungk, who transformed himself from the herald of nuclear research, who launched the legend of the passive resistance of German nuclear researchers to the Nazi atomic bomb project, into a shrill Cassandra.

Of course, it would be unfair to ignore the fact that constructivist working hypotheses can be used to discover many things in the history of technology and sometimes lead to politically explosive punch lines. Even in many technical details of nuclear power plants - especially in the area of safety precautions - one searches in vain for a pure logic of the laws of nature as imagined by the non-technician, but repeatedly encounters norms that cannot be deduced directly from research results, but have to be negotiated. None other than the long-standing nuclear minister Balke, a chemist by training, stated bluntly that one should not imagine that tolerance limits for emissions could be justified on scientific grounds.

However, the crux of the matter is that such negotiation processes are not at all easy to identify and prove empirically. Outwardly, the authority of experts is invoked; as a rule, the negotiation processes take place behind closed doors and are rarely recorded in writing in a way that is readily transparent. Again: the true discourse histo- rician in the spirit of Foucault must develop a detective's instinct and be able to decipher. Where constructivism instead becomes an ideology that denies the existence of mute realities and contents itself with paraphrases of a few writings, it degenerates from a research strategy to a research avoidance strategy.

Friedrich Theodor Vischer (1807 - 1887), professor at the Stuttgart Polytechnic, coined the term "treachery of the object" in his novel *Auch einer* (1879). This is also one of the leitmotifs of a realistic history of technology. And also the saying about the "devil in the detail". Once again, nuclear technology is paradigmatic, especially as it has been scrutinized more closely than all other new technologies as a result of the nuclear conflict. The safety of nuclear power plants depends not only on nuclear physics theories, but even more on often inconspicuous details, especially the stability of certain materials, and it was a decisive step forward in the previously not very philosophical "safety philosophy" to include such criteria.

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This sheds light on how much the historian of technology still needs a keen eye for technical details. If they content themselves with the mathematical analysis of word figures, they fail to recognize the treachery of the object. And he doesn't notice that there have been quite a few technology discourses in the public domain with little reference to reality, whether about robots, automation, cybernetics, human-machine hybrids or artificial intelligence. The latest surge in automation driven by the "digital revolution" in particular shows that when the facts are finalized, the great silence typically begins, at least in public. But this is precisely where the new technology takes on historical significance!

Jacob Burckhardt once predicted that the 20th century would be a time of "terrible simplificateurs", the terrible simplifiers. In today's German humanities and social sciences, however, we tend to have the problem of terrible simplifiers: in social science technology theory as elsewhere. Sidney Pollard liked to begin his expert opinions on theory- and jargon-laden qualification papers with the remark:
"Basically, the author's thesis is quite simple." In many cases, this was charmingly formulated, as the substance of the work was often reduced to a few banalities in plain language. Those who don't have much to say tend to engage in verbal escapades. But the history of technology is complicated, especially when you go into detail; that's why you have to try to keep your style as clear and simple as possible.

The French physicists Alan Sokal and Jean Bricmont mocked the "elegant nonsense" (*Fashionable Nonsense: Postmodern Intellectuals' Abuse of Science*, 1998) that arises when humanities scholars snatch up any scientific figures of speech and turn them into mere set pieces for fashionable pseudo-nonsense. Anyone who only juggles with words and loses all sense of meaning in the process falls for nonsense. In fact, the gap between the "two cultures" cannot be bridged with verbal tricks. Much has been sinned against in this respect for some time.

So let's make the history of technology understandable! But this brings us to a tricky question: What does "understanding" mean in modern technology? Droysen once made understanding the cornerstone of his doctrine of the justification of the historian: "His righteousness is that he seeks to understand." The nature of the old steam engine could also be understood to a certain extent: It converted heat energy into kinetic energy. It thus inspired generations of physicists to speculate about energy as a universal driving force, indeed a substance of technical processes. But what about today, when we are sitting in front of our screens? I have been handling the mouse for ten years without understanding its nature. Is there anything to understand at all? Or is this the essence of modern computers, that you can work with them, but you can't understand them?

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but cannot understand - that competence alone has a practical, not an epistemological character? Are human scientists blocking themselves by always seeking to understand in the old sense?

Mercedes Bunz, born in 1971, co-founder of a "newspaper for electronic aspects of life", begins her *history of the Internet* - and she really wants to "tell" history - with the paradoxical remark: "You have to understand something about the technology of the Internet to be able to observe yourself and others to see what ideas they come up with when it's not about understanding it, but about using it." Again: Let's try to understand the history of technology, even if it's only to get food for thought and to be amazed when we use technology - understanding is only a project worthy of science when it stumbles and struggles with non-understanding.

Last but not least, the history of technology as a human history, not as a fetishistic cult of things, is centrally the history of *work*. Work experience is the historical-processual element in technology far more than physical theory. I owe a great deal to my old friend and long-time colleague Thomas Gorsboth and his many years of experience in advising works councils and in labor law conflicts for keeping a feel for this in the thin seminar air. He was involved in the creation of the first version of this book over 20 years ago, and it is not least thanks to him and his intimate knowledge of the new world of work that I have caught fire again with this subject matter and cannot let it go.

2. The slow progress of the steam engine or: technology as a driving force and technology as a sensation

"Let steam come, and everything in the Occident will be accelerated as if by magic": this is how Braudel concludes a chapter of his famous history of civilization, which presents energy as the "key problem" of the early modern era. "The steam engine was the prince who woke the Sleeping Beauty of industry from her slumber": Matschoß wrote in his History of the Steam Engine (1901), the founding opus of the German history of technology. The steam engine was the "primum mobile of factory industry", wrote the *Allgemeine Preußische Staatszeitung* in 1822, assigning to steam the place previously occupied by God in the mechanistic world view.[1] All this corresponds to a popular idea in which technology is not only made up of individual machines, but in its entirety is a mega-machine.

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nery, which needs ever more powerful drives to increase performance. The result is an energetic view of history, with growing energy availability as the driving force and new forms of energy conversion as the founders of the era. That was something new at the time. Previously, the sight of the pendulum clock, the most complicated mechanism of the early modern era, had led people to believe in perpetual motion, according to Francis Bacon in his futuristic novel fragment "New Atlantis" (1624). Power generation was not the problem then. The steam engine did not immediately revolutionize the economy, but it did revolutionize future prospects.

In Germany, however, the construction of the first steam engines was slow and did little to get things moving. When the first Newcomen steam pump in Central Europe was built in Königsberg, Slovakia, in 1721, it was a baroque prestige project that technicians warned against. The steam-powered pump, which was usually only profitable in coal mines, had to be fired with wood, and its economic absurdity warned against further innovations of this kind. The first German steam engine was the steam pump built at the Hettstedt copper shale mine between 1783 and 1785 on the orders of Frederick II. The construction was preceded by almost 14 years of debate. Heynitz, then head of the Prussian Mining and Metallurgy Department and also the War Department, was already "jubilant" about the 1:6 scale model of the machine. However, the construction and initial operation of the steam engine was fraught with difficulties and cost an enormous amount of money. In 1794, the steam pump was broken off again and relocated to a coal mine.

The whole process had as much of a deterrent effect on private entrepreneurs as possible. It was not the starting signal for an "industrial revolution"; on the contrary, the spread of the steam engine in Prussia was slow until the 1950s.[2] "To put it bluntly, one could say that Prussia assumed its leading role in mechanical engineering from the middle of the 19th century not because of, but in spite of its early steam engine constructions." (Wolfhard Weber)[3] If one were to look only at the steam engines, the rapid industrial rise that followed would seem like a miracle.

For Landes, as for other historians, the procrastination and ineptitude in the introduction of early steam engines revealed the underdeveloped state of technology in Germany at the time: "This was the pre-homeric age of industrial Germany, when steam engines went through odysseys and became the subject of legends for later generations." And yet there was already a wealth of industrialization approaches and attempts at innovation in Germany at that time. It was precisely the reluctance to use the expensive and fuel-guzzling steam engine

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can testify to technological competence, while naïve enthusiasm for the most expensive and sensational technology often betrays a lack of technical experience.[4]

Pastor Schwager was overcome with a holy shiver when he inspected the famous steam engine at the Königsborn salt works near Unna in 1802. Johann Beckmann, on the other hand, who founded "technology" as a separate subject at German universities in the late 18th century, barely mentioned the steam engine in his tireless literary output. This can be explained by his fundamental aversion to complicated machines, which were "too artificial, too precious and too fragile". He certainly recognized the advantages of the steam engine in England, but in 1806 he posed the rhetorical question: "Where would we get the fire for this, which we can hardly afford to heat!"[5] At that time, many people in Germany still assumed that steam engines in this country had to be fired with wood. However, converting thermal energy into kinetic energy was absurd in the "age of wood", when thermal energy was a scarce commodity unless the forests of Russia or North America were available. At the end of the 18th century, warnings about wood shortages were commonplace in Germany.[6]

For Beckmann, it was already a familiar experience that technical innovations were accompanied by a torrent of journalistic hogwash and that some writers made indiscriminate propaganda for the latest foreign inventions their business. "One must marvel at the impudence with which ignorant people recommend their inventions; as well as at the impudence of those who translate descriptions of foreign data without having the slightest knowledge of the subject matter." He emphatically explains that even if machines really did have the claimed advantages, these were often bought with disadvantages elsewhere. Beckmann's student Poppe repeated this warning (1812). He believed that steam engines could "never be used as generally in Germany as in England" due to their fuel requirements.[7]

The official German report on the London World's Fair of 1851 stated that it was by no means to be expected that Germany would ever reach the English level of coal and iron production; it did not have enough coal for that.[8] It was only in the following period, when the Ruhr mining industry pushed into deeper seams, that an epochal change took place in Germany's industrial and technological profile: Germany became the land of coal and steel.

Even in England, steam engines only spread slowly at first; they only became generally accepted in the course of the 19th century.

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of the past. The early textile factories were driven by water wheels and continued to use this source of power where there was plenty of water power until well into the 19th century: No technical compulsion led to the steam engine. Even in the early centers of the German textile regions, in the Bergisches Land and in Saxony, the sensible rule was to stick to low-cost water power for as long as possible, especially at a time when coal could not yet be transported by cheap rail. If a steam engine was nevertheless procured, it was often initially only as an auxiliary device for seasons with little water or out of a certain need for prestige. Measured by the efficiency of energy conversion, the use of water power was far more advanced than steam power. Around 1840, the brothers Werner and Wilhelm Siemens worked on the "exact regulation" of steam engines that were combined with wind or water mills.[9]

It is doubtful whether the initial failures of the steam engine indicate a low level of technology in Germany as a whole. The steam engine is not an indicator of the general state of technology around 1800, not even in England, just as the Sputnik in 1957 did not represent the general state of Soviet technology. Moreover, steam engine construction did not pose any insurmountable difficulties in Germany at the time either, as soon as practitioners pursued it in their own interests. In the literature, the initial misfortunes are often dramatized along the lines of "through struggle to victory". What is more remarkable, however, is how quickly steam engine construction succeeded as soon as there was a strong demand.

The Rhineland journeyman carpenter Franz Dinnendahl, who inspected the new steam engine at the Königsborn salt works near Unna around 1800, boasted:
"[n]o sooner had I looked at it for an hour than I was so familiar with it that I felt strong enough to build a similar machine. "[10] This was no mere boast: Dinnendahl and his brother Johann had been building functional steam engines for decades, even without English help. In the German mining industry, where the early steam engines were used as pumps, technical developments abroad had always been closely followed; Newcome's steam pump was well known there. But even in the 18th century, elaborate water supply and drainage systems were still being developed in the Harz Mountains and around Frei- berg; horse-drawn pumps were used in the Mansfeide copper mine until 1866. Johann Dinnendahl gave up steam engine construction in 1837 and became involved in mining and metallurgy without any luck.[11] From the perspective of the time, the steam engine business did not necessarily offer attractive growth prospects; other areas promised more.

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It was not technical difficulties, but the cost of fuel and the lack of usefulness of this propulsion power for small businesses that hindered the implementation of the steam engine in Germany. The first German steamships (1816/17) remained obscure and were soon scrapped again: there was so little real need for them.[12] A realistic history of technology is not only a history of inventions, but also one of the development of needs. Georg von Reichenbach, the son of the "Ober-Mechanicus" of all military workshops in Bavaria, who was technically very capable of manufacturing steam engines due to his experience in cannon construction, tried in vain to construct a steam engine that could be used in small businesses, i.e. one that was adapted to the Bavarian economic structure; in contrast, he built a water column engine driven by water pressure for the Berchtes- gaden-Reichenhall brine pipeline in 1816, which was considered "the largest engine in the world" at the time.[13] Even in Germany at that time, large-scale technical achievements were possible in the use of water power and in the sovereign mining and saltworks industry.

An article in *Dingler's Polytechnisches Journal in* 1825 calculated that steam power was almost twice as expensive as horse power in most German regions. The "size of the capital investment" and the susceptibility of this machine to repairs were also disadvantageous. Joseph von Baader, the leading Bavarian technologist of his time, saw himself challenged to lively opposition: Not only did the cost calculations not apply to many areas; the lack of growth potential of the "horse arts" was also being overlooked. A steam engine of 60 hp was not a huge work; on the other hand: "But how monstrous, clumsy and unhelpful would a horse art turn out in all its dimensions, on which 60 horses work at the same time?" That was the crux of the matter: the steam engine gained a fundamental advantage as soon as people started thinking in terms of growth and smooth organization. This was particularly true for regions in the lowlands where there was a lack of water power and where the steam engine competed not with water mills but with the more expensive windmills and horse-drawn mills. It therefore applied to large parts of Prussia, not least Berlin.[14]

The use of hydropower was also developed with great success in the 19th century.

Further developed with vigor. Here, however, efforts were split along different paths: the further development of the water wheel, the water column machine and the turbine. When setting up a new hydropower plant around 1850, it was very difficult to decide which technology to choose. General rules did not help; everything depended on the specific local conditions. At that time, steam power was simpler, more compact and more location-independent.

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The steam engine was closely linked to the rise of the "mechanics" to "engineers". For the engineers of the 19th and early 20th century, an improved design of the steam engine was the masterpiece par excellence. In many other areas of technology, the tradition of craftsmanship still dominated for a long time; it was not easy for engineers to prove that it was not only manual skill and practical experience that mattered, but also knowledge and training. They were able to demonstrate their superiority most impressively with the steam engine. This image of history, in which the steam engine is the driving force of industrialization, has its social basis here.[15]

Steam engine construction was also largely a matter of practical experience, especially in its early days. In his *Wealth of Nations* (1776), the bible of economic liberalism, Adam Smith mentions the steam engine - surprise! - only as an example of the inventions that workers, even children, were capable of:

"With the first steam engines, for example, one boy was constantly busy alternately opening and closing the passage from the boiler to the cylinder when the piston went out or down. One of these boys, who preferred to play with the others, observed the following: If he connects the handle of the valve that opens the connection to another part of the machine with a string, the valve opens and closes by itself, leaving him time to play with his friends."

Child's play as the origin of the most famous automatic self-regulation system in early industry! Steam engine construction only became a task for science when efforts were made to optimize efficiency, increase steam pressure accordingly and at the same time increase explosion safety. This was the point at which independent German steam engine development began, because in many German regions it was more important than in England to use fuel sparingly, i.e. to increase efficiency, and here an engineering profession emerged that saw its future and its particular strength in science.

Ernst Alban (1791 - 1856), the first German pioneer of the high-pressure steam engine, already took the American Oliver Evans as his role model and was one of the first German engineers who were no longer fascinated by the rapid progress of English technology, but noticed the increasing conservatism of British mechanical engineering. He constantly mocked the exaggerated external expense and unnecessary complication of English steam engines and explained the increase in efficiency - "to achieve the highest purposes with the simplest possible means".

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to the basic task of technology. He mocked the lack of technical rationality in English factories:

"Every day you see the most absurd combinations between steam engines and the works they operate. One of the most common is that of operating pumps by steam engines with circular movements. Here, a straight-line movement is transformed into a circular one in order to derive a straight-line movement from it. Can you think of any greater nonsense?"

He himself prided himself on not building one steam engine like another, adapting each one to its particular purpose and planning the entire system in a uniform way. The leitmotifs of the rising German mechanical engineering industry are clearly articulated here for the first time: flexible adjustment to requirements, the pursuit of theory and systematics, the adoption of American models of rationalization and their adaptation to German conditions. Nevertheless, the high-pressure steam engine was slow to catch on. Alban made his profits with agricultural machinery driven by animal power. However, as the early high-pressure steam engines were associated with a high risk of explosion - one critic spoke of a "terribly overloaded steam cannon" - the slowness of progress was well-founded, indeed a prerequisite for success.[16]

The German hesitation towards the steam engine until the middle of the
In the memory of the period that followed, the 19th century quickly became a sign of past backwardness that had now been happily overcome. This even applies to the view of many workers. In 1846/47, the grinders of the Bergisches Land, who felt that they were their own masters in their water-powered grinding cottages, still resisted steam-powered grinding and the associated factory system, as they had no desire to "work to the whistle under the monotonous sound of steam and have their independence covered with a shroud". However, they soon learned to retain some of their autonomy even under the conditions of steam operation.[17] In general, the steam engines did not meet with the same hostility from the workers as the early textile machines, as they replaced more horse-drawn galleys and water wheels than people and, in the case of human labor, not manual dexterity but mechanical drudgery.

When the rebellious weavers of Langenbielau came to the steam engine after the looms in Dierig's factory had been smashed, they stopped and shouted to each other that it was "very nice". In the sixties of the 19th century, locksmith apprentice Hermann Enters felt that all businesses without a steam engine were inhumane, as the apprentices were burdened with the dull, tedious drive work.[18] Farm worker Franz Rehbein, who worked on the large Holstein farms already equipped with steam threshing machines at the turn of the century, despised the "püttche-

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He lived on the "old" southwest German farms, where there was almost no "modern" farming equipment. In his memoirs, he commented briefly and fatalistically on the fact that his right arm was torn off by a threshing machine (which could have been prevented even then by feeding the grain mechanically): "Workers' fate!" Getting used to the steam engine changed the way work was perceived. The trend that not only heavy "backbreaking work", but ultimately physical labour in general was perceived as a flaw and a mere "stopgap of mechanization" continues to the present day.[19]

Figure 4: Steam threshing machine on a Franconian farm: photo from the early 20th century. Steam threshing machines were a popular photo motif; here, as in other photos of this kind, the family (or even several farming families), the servants and the seasonal workers pose around the machine. As the individual farm could not afford such a machine, the farmers formed threshing cooperatives. Steam power displaced animal and human power only to a limited extent; at least in the photos, it appears to be an integral part, even the pride of farming society. This was not always the case; in the 19th century, the peasant classes regarded the threshing machine as a threat; it was only later that threshing with the flail became the epitome of primitive backbreaking work. Although the electrification of the farm economy had been the preferred topic of electrical advertising since the early 20th century, it only became a widespread reality in the second half of the century.

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The steam engine was the idol of a picture-book-like history of technology which, for lack of complex ideas about the technology factor, stuck to the externally impressive. Steam as the driving force of the "Industrial Revolution": this is a prime example of the technological illusion that often obscured the fact that it was not monstrous mechanisms that mattered, but the perception of market opportunities and location advantages, work experience and organization. The emphasis on technology often characterized a superficial way of looking at the history of industrialization: As a result, the history of technology long possessed something old-fashioned and primitive from the perspective of the social and economic historian.[20]

But the example of the steam engine is also suitable for revealing the technical aspect of history in a broader sense: the connection between technical development and the social history of engineers, the significance of the "scientification" of technology, the emergence of *economies of scale* with their technical moments, the change in the experience of work and the change in human perception through the machine. The history of the implementation of technical innovations becomes revealing when it is not written with an impatient undertone as a story of progress that is repeatedly held up but finally triumphs, but when the rationality of caution is also discovered. German history in particular contains not only traditions of a romantic, culturally critical hostility to technology, but - more importantly - examples of an expert and discriminating skepticism that came from practical experience. It was not without reason that the Germans were considered a "slow" people in the 19th century; this slowness was not only a disadvantage.

Paulinyi has rightly pointed out that the "one-sided emphasis on the steam engine obscures the essence of technical progress in the Industrial Revolution".[21] If the fascination with certain spectacular technologies is overcome, the view opens up to the entire breadth of technical development and a concept of technology is gained that corresponds to the diversity of historical reality. It is not only the leading technical sectors that are important for the historian, but also the more traditional areas, all the more so as statistics often show that the overall economic significance of cutting-edge technologies is far less than many believe and that the alleged "leading sectors" are far from advancing all parts of the economy, but are even setting some back. "Success" often has something to do with technical versatility and a combination of conventional and new technology appropriate to the situation. German technological history offers impressive examples of this.[22]

The steam engine was not the driving force behind events, but neither was it a mere reflection of economic need. If one only wanted technology

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If we were to understand technology as a mirror of social structures and intentions, we would understand the treachery of the object and the scope of unintended technological consequences. The role of technology cannot be accommodated in a simple causal or reflection model of history; instead, we need models of interaction, reinforcing feedback and synergy. The machine is not a motor of history; but economic power structures, social mentalities and technical communities crystallize around certain technologies. Technology is an element that creates cross-connections,
"alternating currents" (Thomas P. Hughes) and networks. In all of this, the metaphor of the "devil in the detail" is justified, because it is not so much the basic technological principles as the details that particularly contain the spatial and temporal nature of technology and, not least, also determine the humanity and inhumanity of technology. The controversy surrounding nuclear energy has had a more enlightening effect than any other technological discourse and has made people aware of the supra-technical significance of even individual technical components: weld seams were seen as risk areas and pressure relief valves as indicators of a new "safety philosophy" that includes the bursting of the reactor pressure vessel. This learning process can be continued into the older history of technology. There is no doubt that the technical details always contain the risk of
"Technology illusion", the pretense of supposed technical constraints. Nevertheless, a certain interest in technical detail is necessary so that the discussion of technology can move beyond the old, unfruitful, culturally pessimistic lament about the "demons of technology" and the more recent generalized oscillation between "risk and opportunity" and focus on concrete alternatives within certain areas of technology.

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I. History of technology and the "German way": Theoretical foundations, models, guidelines

1. "Adapted technology" in the past - the regional approach in the history of technology

The aim of this presentation is to provide an overview of the history of German technology and at the same time to discuss the role of technology in German history. In doing so, the question of the "German way", which is passionately discussed in intellectual and political history, will be introduced into the history of technology. "German way" is understood in several senses and not immediately with a positive or negative evaluation: both as the shaping of technology by German ideologies, social structures and power relations as well as the adaptation of technology to German location and environmental conditions. The analysis of national styles of technology can lead to a more comprehensive and colorful picture of the relationship between history and technology, but can also provide clues for the critical evaluation of technical developments.

There are a number of objections to this project, in particular the view that technology is supranational in nature and that national influences are only superficial and temporary. Indeed, at first glance, especially from a global perspective, the impression of the civilizational and thus also technical affinity of Central and Western Europe and North America is overwhelming; one can even recognize a rapidly increasing convergence in the course of the explosive growth of trade relations after 1945. The spread of Western civilization throughout the world and its similarity even in exotic environments is a phenomenon that is more striking than ever, especially in recent times. As early as the 19th century, it was often remarked how fruitless it was to argue about the priority of this or that nation for certain inventions and how impressive, in contrast, the coincidence that similar inventions were made in several nations at the same time and often complemented each other. Even at the height of nationalism, this technological interplay between nations was always recognized and perceived as significant: Here, the techno-

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progress as a natural process that transcends national boundaries.

Recently, Wolfram Fischer highlighted the "convergence of productivity levels" as the "most important result" of a study by Angus Maddison, which compares the development of labor productivity in 16 countries over more than a century: a reason to assume that the technical equipment of these countries has also converged. According to Fischer, technical advantages are rapidly melting away and innovations are spreading quickly within industrialized countries. The "technology transfer" seems to have become an almost mechanical process, just as this overused term has suggested for some time. However, due to many disappointing experiences in development aid, the adaptation of technology to regional conditions has become a major issue. The history of technology in the leading industrialized nations can also be rediscovered from this perspective: it will often be found that they did not simply import technology, but rather adapted foreign technology to their own environment.[1]

The striking industrial rise of Japan and South Korea has made the importance of cultural traditions for economic and technical development even clearer. However, national peculiarities are not only rooted in tradition and are not necessarily eroded by international exchange. It is precisely through growing foreign relations that the international division of labor is strengthened and national profiles emerge that did not exist in the times of sparser communication. One hundred years ago, it was expected that the trade of the future would mainly take place between industrialized and raw material countries; in reality, trade between industrialized countries experienced the strongest growth: increasing world trade promotes diversification between nations. Michel Foucault commented on the "Paris-Berlin" exhibition to *Der Spiegel in* 1978: "We see that we were very similar to the Germans when we were killing each other, and far apart when we were getting closer."

In both German and Japanese industrial history, periods of imitation were followed by periods of a pronounced striving for independence, not only in the era of nationalism, but right up to the present day. Around 1900, German machine tool manufacturers looked to the USA as if spellbound; today, the German machine tool industry is more self-confident than ever before in emphasizing the "German way" of flexibility and small series production compared to the USA. From the 1920s to the 1950s, there seemed to be no higher goal for the German automotive industry than to imitate, albeit imperfectly

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Ford; today, economic historian Werner Abelshauser attributes the high level of unemployment in Germany primarily to a forgetful adoption of the Fordist model of uniform mass production. As in the mechanical engineering industry, the German automotive industry in the 1980s also spoke of the "German way", the "German model", which corresponded to the qualities of skilled workers here. The hunt for competitive advantages on the world market intensified the search for "unique, unmistakable characteristics"; this search was partly carried out on a national scale.

But the politicization of new technologies also works in a similar direction. An ideal-typical contrast has emerged between the development of nuclear energy in Germany and France, the like of which has rarely been seen in the history of technology. This is not surprising in nuclear technology in particular, because the more the technology is subject to political influences, the more extensive its systemic character becomes and the more important the safety problems become, the clearer the national character of the technology becomes. Although the Federal Republic of Germany imitated American reactors in the 1960s, it was complained in 1979 that the "increasingly divergent requirements in the USA and Germany" were leading to "an ever greater divergence between the two technologies". In 1989, a Siemens director described it as his "greatest aha experience" when he observed in the USA how little skilled labor experience and precision was required to build nuclear power plants there.

Wolfram Fischer drew the practical conclusion from the convergence thesis,

"that no one can sleep, because the international competition is hot on their heels". However, if one assumes that there are a multitude of different paths to success, one comes to the conclusion that the technician can also allow himself a peaceful night's sleep. German history after 1945 in particular shows how quickly a technical backlog can be made up if a broad, well-trained workforce is available and the necessary demand exists. The example of England, on the other hand, shows how success carries the seeds of stagnation and decline. Surely a warning for the Germans too!

In recent times, the historiography of technology has repeatedly tried to focus on national "technological styles", "technological cultures" and "technological contexts"; but so far it has had difficulties in concretizing these still floating concepts. Is the idea of technological progress getting in the way?

Research into the history of technology, as it is established internationally today, is to a large extent a product of the late 1950s and early 1960s.

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years: the time of the "Sputnik shock", the discovery of the "technological gap", the beginning of the high-tech arms race.[2] Their classic theme is innovation, and traditionally their tendency is to attribute success to innovation and failure to innovation inertia.

By projecting innovation and economic curves onto each other, Gerhard Mensch attempted to prove historically that only fundamental technological innovations ("basic innovations") could lead to new prosperity from the economic downturn. However, depending on what one defines as a "basic innovation" and when one dates its implementation, one arrives at very different curves and could, for example, prove that the global economic crisis was preceded by a significant innovation surge, while the historically unique economic boom of the 1950s and 1960s was essentially based on the broad use and further development of known technology.[3]

Since the 1970s, when the slogan "small is beautiful" also became popular in the Federal Republic of Germany, interest in traditional and everyday technology has increased significantly. The boom in regional and local exhibitions and museums, illustrated books and all kinds of "trace evidence" has reminded us that techniques and working methods that seem archaic today have survived well into our century. The conventional fixation of technological literature on the most modern technology distracted from the fact that a production method that lagged far behind, combining the modern and the traditional, was often more typical and had its own rationality.[4] The exhibits in technology museums often have a regional flavor, but there is no concept of regional technology.

What can be region-specific about the technology? As a rule, not the basic principles, but the ensemble and many details, the combinations and cross-connections, the environmental relationships, dimensioning and design, materials and building materials, the use of energy and water, the "man-machine system". The regional approach conveys a more comprehensive picture of technological change, because the dynamics of technological development cannot be demonstrated by individual technologies alone, but only by the "cross-fertilization of technologies" (Pollard) and the way in which the technological level of a region develops on a broad front.[5]

This applies to Germany as a whole as well as to regions within Germany, and not only for early industrialization, but also for the present. Recently, it has even become fashionable to exaggerate the technological profile of German regions by way of contrast and to juxtapose the outdated old technology in the north with the high-tech strongholds of the south.[6] The technological revolution that has been driven by electronics has been a major factor in Germany's industrialization.

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he trend towards networking is giving new impetus to the regionalization of technology: "Only regionally coordinated and practical system solutions," says an expert in production systems, could advance the integrally computer-controlled production method. "Region" has recently become a magic word in future-oriented industrial structure policy. The technological rise of southern Germany sheds new light on the past. When Schnabel wrote that "technical development could not be continued" in Bavaria "because there was no coal", "this primal material of modern times", the lack of the pull of heavy industry in southern Germany has long since turned into an advantage.[7]

The possibilities of the regional approach are only inadequately exploited if it merely amounts to addressing the lead of one region and the relative lagging behind of another in the context of the progress, growth and race paradigm, instead of investigating whether the lacking or only partial reception of new technology did not correspond to certain conditions of a region, and whether the successful "technology transfer" did not also involve certain modifications of the transferred technology.[8] This is where the regional approach meets the more recent discussions on "adapted technology".

The concept of "*appropriate technology"* was originally developed for the "Third World" in response to unfortunate experiences with highly complex technology adopted unchanged from the West. *Appropriate technology* in this case means simple and cheap technology that corresponds to the regional resources and needs, the labor force potential and the environmental conditions. However, pragmatists also understood "adaptation" to mean an orientation towards export opportunities, especially if these were specific opportunities for a country, relatively competition-protected niches. European countries and even a country like Canada, which knew how to assert themselves against powerful neighbors by successfully exploiting "technological niches", were discovered as role models for today's developing countries.[9]

"Adapted technology" was elevated by the protest movement against nuclear power to an ideal for highly industrialized countries. The concept often had utopian traits: it was a technical version of ecological wishful thinking. Initially, there was no relationship to history; for many supporters of *small technology,* the technology of the industrial past was under the curse of *economies of scale*. Many pioneers of "adapted technology" developed their concept in a way "as if history simply did not matter" (Langdon Winner).[10]

However, there is reason enough to add a historical dimension to the concept of adapted technology: History offers a

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examples in abundance, but also shows the ambivalence of what means "adaptation". Piore, Sabel and Zeitlin have reminded us that in the course of industrialization, alongside the trend towards mass production and large-scale industrial complexes, there were also repeated trends towards small-scale craft businesses: not out of pure traditionalism, but out of flexible adaptation to a variety of newly emerging market niches.[11]

The fact that the technology had to adapt to regional conditions was In many cases, this was so self-evident in the 19th century that it hardly needed mentioning; what was more striking was the import of technology from abroad. The locally available stones, types of wood and qualities of iron shaped the technology everywhere, from the tools to the blast furnaces. Adaptation of this kind and adaptation to the available workforce corresponded to the old mercantilist maxim that technology should primarily use local resources and increase product quality, but not make people unemployed.[12]

Even in the age of the railroad, it was a truism that a country's transport system had to be adapted to its natural characteristics. "The form of a country's transportation system," taught Max Maria von Weber, "is just as necessarily the consequence of its climate, soil, weather conditions and form of government as the physiognomy of its animal and plant forms is the product of its entire nature. "[13] Even into the 20th century, it was taken for granted that agricultural technology and cultivation methods had to correspond to natural conditions. In his standard work on the *national economics of agriculture* (1859), Roscher mentions - in contradiction to agrarian reform myths - as a lesson of history "that the majority of such colonizations, which were brought from a highly cultivated region to a low-cultivated one in order to serve as models of better agriculture, did not want to thrive. In general, they languished, required constant subsidies and could only rise in the next human age when they had merged with the customs and economic methods of their new homeland." As you can see: Many disappointments of "development aid" could have been avoided with a knowledge of history free of myths! It was only in the divided Germany of the 1960s that agricultural and transport policy - most strongly in the West - began to be determined by a completely different way of thinking. But even the founding fathers of the "social market economy", which marked the beginning of the German "economic miracle", were well aware of the link between the economy and technology and society and culture. Wilhelm Röpke accused Keynes, the theorist of state-driven development, of having contributed to a "stubborn error" when he "in one of his less enlightened hours spoke quite unconcernedly of the need for a social market economy".

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that "modern technology [...] has allowed industry to spread across the whole world".

"Adaptation to nature" could also be defined in terms of international trade. When liberalism called for an industry in line with "nature", this "nature" did not encompass the entire endowment of a region, but rather its advantages over other regions, which came into play in an interregional division of labor. When the pastor Schwager asserted in 1804 that the "good Lord" and "nature" had allocated "to each country its special treasures" and "to each nation its own industrial spirit", this was in the context of a polemic against the "ridiculous quixoticism" of mercantilism of wanting to "have all factories in one's own country". And when Walther Rathenau proclaimed in 1918 that every industry was "a product of the soil, no different from animals and plants", this was a plea for large-scale industrial concentration at the most favorable location. In the eyes of the chemical pub- licists, Germany, which was poor in raw materials, was predestined for chemical synthesis due to its natural conditions.[14]

Gerschenkron even believes that the large-scale technical projects of tsarist and Stalinist Russia contained a sensible assimilation of foreign technology; for it was precisely the most modern, most compact, most labor-saving technology that corresponded to the pre-industrial environment and the lack of qualified skilled workers in Russia.[15] Here, however, "assimilation" basically means adapting the technology to the conditions of its own functioning. The Stalinist type of industrialization in particular can be seen as a true nightmare of unadapted, ultimately murderous technology. When Gerschenkron refers to the German model, it should be noted that the success of German industrialization was based not least on the fact that not all forces were absorbed by large heavy industrial complexes, but that at the same time a strong intensification of agriculture was achieved and craft traditions were kept alive by a large number of small and medium-sized enterprises.

In all attempts to define "adapted technology" and the national profile, the regional style of a technology, a tension arises between the internal and external view of the region: the picture becomes different depending on whether one defines the "nature" of a region from the totality of its conditions or from its relative advantages in the context of an interregional division of labor. The ideal would be a type of industrial development that harmonizes domestic conditions with global market opportunities. Recently, however, the tension between these two criteria has become more acute; under the spell of the global market and the European single market, the question of adapting technology projects to German conditions is often no longer even asked. In one decisive point

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However, the internal and external perspectives meet: in the fact that the "human resource" is the most important German location condition. Nowadays, however, this insight often remains without consequences.

What "adapted technology" means can be recognized above all by its disadvantages. This applies not only to underdeveloped countries, but also to overly successful industrialized nations that lose a sense of the limitations of their technical possibilities. There is no shortage of examples in recent German history: American-style mass motorization with its urban-destroying consequences; the over-engineering of agriculture encouraged by subsidies; the adoption of American nuclear technology, although the densely populated Federal Republic could not adopt the American distance criteria; the growing aviation ambitions, although an ever-increasing expansion of air traffic in the confined space of the Federal Republic creates horrendous problems; and last but not least, the waste of the most important resource, people, through the neglect of specialist training and through organizational-technological strategies that predominantly amount to the release of workers. Last but not least, the signs of crisis in the present provide impetus for a rediscovery of the history of technology.

2. On the discourse history of the "German way" in industry and technology

The most colorful genre of literature on the subject is comparisons between German industry and that of other countries, often from the perspective of competition. While academia generally struggles with methodically exact comparisons, the comparison of nations has been an inexhaustible topic in popular literary genres written from the 18th century to the present day: one for travel and exhibition reports, for trade agency reports, for journalistic warnings and wake-up calls. The impetus came not only from economic rivalry, but also - especially in the
20th century - also the arms race and the war-related experience with the technology of other countries. From the 19th century onwards, the stream of reports on England that began in the 18th century was joined by ever new waves of reports on American industry and technology, often combined with assessments of German weaknesses and strengths. From the middle of the 19th century onwards, the world's fairs indulged in a picturesque panorama of the technical excellence of many nations and provided a constant stimulus for trenchant comments on national technical profiles. The

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Differences in the development of railroad systems prompted comparisons between the state of the art in different countries.

The terrifying mechanization of warfare during the First World War, the spectacular incursion of Fordism and Taylorism into Europe in the 1920s and the proclamation of a "German technology" by National Socialism triggered streams of literature that always focused on the performance of German technology and production methods in comparison to those of other countries. Since the 1960s, the heated debates about Europe's *technological gap* with the USA and the debates about armaments and nuclear technology have provided new impulses of comparable intensity. The rise of Japan - in some respects analogous, in others a mirror image of the German "economic miracle" - also shed new light on German events. Travelogues, although less famous than in the 18th century, have not lost their significance. The extremely high export orientation of the Federal Republic led to a permanent and nervous comparison of Germany's performance with that of Japan, and now even more so China, and the USA, which was always open to alarm calls. The globalization rhetoric of recent decades is forcing a redefinition of Germany's profile on the world market, because the German opportunity obviously does not lie in imitating the Chinese. National and supranational large-scale projects in new technologies are also likely to stimulate a national technological profile neurosis.

From a historical perspective, it is not without amazement that today, in a Technological innovation as such - regardless of costs and demand, human performance and the civilizational environment - is being made the main topic, the subject of politics and the panacea for crises to an extent never before, although the growing share of the service sector is tending to reduce the economic significance of production technology.

The German discussions are juxtaposed with similar ones in other countries; there is often a correlation. Is this essentially an escalation of nationalist prejudices? But it is not as easy to project stereotypes into technology as it is into national characters. In essential points, self-assessment and external assessment of German technology coincide. Some judgments vary depending on whether Germany is characterized from an American, English or French perspective. Looking at the USA, Germany used to complain about the excessive variety of products and lack of standardization of German manufacturing methods; a French observer, on the other hand, admired the spread of series and flow production in the German Reich as early as 1914.[16] Robert Brady, the American historian of the German rationalization movement, noted that German consumer behavior was not so individualized

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as the Germans liked to imagine.[17] In recent times, the lament about Germany's lagging behind the USA and Japan in electronics has become commonplace in the Federal Republic; from an English perspective, however, the Germans have followed the American and Japanese semiconductor industry with considerable speed.[18] Sometimes different nations are assigned to each other in a dialectical figure: the Germans as the people of meticulous thoroughness, the Americans as the people of innovative but unsound hecticness, and the English in a position between the extremes[19]; American electrification as unilaterally determined by economics, English electrification as unilaterally determined by communal politics, German electrification as a successful combination of economics and communal politics; the spirit of British engineering as practice without theory, French engineering as theory without practice, German engineering as a synthesis of the two.[20] However, all these ideas did not completely congeal into stereotypes, but were exposed to confrontation with practical experience.

The causes of Germany's success in England were discussed particularly persistently and passionately: in the debate about the decline of British industry, which was only claimed for a long time but actually occurred in the end, from the late 19th century to the present day. Until the 1980s, the fate of England was presented as a warning example of the evil consequences of inertia in innovation; however, a similar argument was made for the relative decline of the British steel industry in the late 19th century. Ulrich Wengenroth has refuted this view and at the same time demonstrated that the "German path" to success here had more to do with cartel and protective customs policies than with technical innovations and special quality work.[21]

In important areas of innovation, England still held a leading position until the 1950s: despite the supposedly secular British backwardness in scientific technology, British chemistry in particular has held its own relatively well to this day. Armaments, aviation and nuclear technology were further developed at great expense: But it was precisely this kind of progress that was not good for the economy as a whole. On closer inspection, the British example demonstrated not so much the fatal flaw of a lack of technological progress, but the harmfulness of one-sided promotion of supposedly cutting-edge technologies in the military interest. To put it bluntly: not too little, but too much "research and development" - often referred to as
"R&D" for short - led to dead ends, as it distracted from the needs of the market.[22] All this gives reason to revise some common views on the causes of success and failure in German technological history, in particular the opinion that German success was essentially based on cutting-edge technology, costly innovations and rapid innovation.

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The pace of innovation was based on a lack of innovation and more recent signs of crisis were due to a lack of futuristic high-tech projects.

Some American interpretations of the "German way" have the advantage of being exemplary, even if they are not always well-founded. Thorstein Veblen (1915) contrasted the "German industrial community", which had placed itself "unresistingly under the rule of the technological expert", with American industry, which was ruled by "financial strategists", as a model. For Lewis Mumford (1934), the German Empire was the country where the rule of "paleotechnology" - "carboniferous capitalism" characterized by heavy industry and the overexploitation of nature - initially (until about 1914) reached its worst perfection, but then "collapsed with greater rapidity than in any other part of the world". In his view, Germany became the country of "neotechnology", the prudent use of residual materials, the chemical utilization of coal, clean electricity.[23] Germany also serves as a role model for Piore and Sabel (1984): This country had never succumbed to the fascination of American mass production. "Compared to all other major industrial powers, the paradigm of manual production remained the most important in Germany." "Germany's suitability for handicraft and small-scale production" had "its origins in the cooperation between the regional small-scale economy of the 19th century, which was similar to that in France, and the almost aggressively efficient state authorities". In the sixties and seventies, the Federal Republic strayed from the good German tradition to its detriment; now, however, under the aegis of flexible specialization, it is on the way back.[24]

For Bruce Nussbaum, editor for international business at *Business Week* "German" and "technology" are traditionally almost synonymous: "Where else is the flawlessly constructed machine so revered?" But the industrial structure centered around "heavy engineering, steel and chemistry", which had become second nature to the Germans and experienced a final high point in the late 1970s, was now, in the era of "new technologies", becoming the undoing. The "German penchant for perfection and order, which proved so outstanding in the mechanical age" is becoming a burden in the age of electronics. The ways out of the misery now sought by the Germans endangered the Western world: the flight of the youth into ecological utopias and the turning of industry towards the East, where the "old 'dinosaur' heavy industries" alone could still hope for a future.[25] But even in the 19th century, the German industrial structure was already partly characterized by relations with the East: This topic is missing from the history of discourse. Nussbaum's much-noticed book in the USA

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This controversy was overtaken by events within a few years. Today, some observers consider the "German way" in the new technologies with its relatively broad base of skilled workers to be more successful than the American way with its high-tech islands isolated from civilian production.

There is no doubt that theses on the "German way" are highly susceptible to criticism, and the chiaroscuro contrasts of the models of Germany presented, with their generalizations and contradictions, invite criticism. There is a danger that reflections on the German in technology will maneuver thinking into precisely the zone that should be avoided: the intellectual climate of the international technology race and technological nationalism. The history of discourse should certainly not be confused with real history. The "German" often has the least substance precisely where it is proclaimed the loudest: in the "German physics" and "German technology" of the National Socialists. The discourse on technology nevertheless contains some corrections within itself. Even in the worst cases of nationalism, the tendency to boastfully overestimate one's own technology was often balanced by the counter-tendency to exaggerate the technical advantage of foreign countries in order to incite national efforts. National Socialism, which proclaimed "German technology", was particularly incapable of a clear and binding definition of "German" in technology.

3. "American system" and "Swiss model": contrasting national styles of technology

In order to clarify the idea of national technological styles, it is useful to take the USA and Switzerland as extreme examples: both countries whose technical-industrial profiles have a model character in very different ways and show characteristic analogies and contrasts with German conditions.

The USA was the earliest country to develop its own distinctive style of production, which not only differed from the English style, but was superior to it in many respects. The *American System of Manufactures* became the archetype of a national style of production to such an extent that the European way of doing business later came to be defined in contrast to the American way: through production on a small scale and small and medium-sized enterprises, through complicated production methods and a high proportion of labor.[26]

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The history of German technology can be traced back to the 1930s.

19. The history of the 20th century, from the beginnings of railroad construction and the machine industry, can be described in one main line as a dialectical counterpart to the development of American production: as the history of a wave of fascination with the USA, of ever new receptions and modifications of American production methods, but also as a history of bouts of Americanophobia and violent counter-reactions to "Americanism". German economists' and technicians' trips and stays in America have repeatedly had a signal effect: from Friedrich List to Reuleaux and Riedler, Duisberg and Carl Bosch to the founders of the German nuclear industry and, more recently, the *New Economy*. The

From the perspective of other European countries, the "German way" often seemed like an adaptation of the American style to a more hierarchical society characterized by respect for formal qualifications and scarcer resources. The Germans were sometimes regarded as the "Yankees of Europe" even before 1914, and not just in the era of the Federal Republic. But the "Americanization" was generally oriented at least as much to an imaginary model of the USA as to American reality.[27] In Germany, it became particularly clear that individual fragments of American civilization in a different cultural context in no way brought about a growing alignment with the USA. German history is perhaps particularly exemplary in this respect, as the love-hate relationship with American civilization has become one of the strongest motives in the world today.

Discussions of the *American System of Manufactures* date back to the time of the London World's Fair of 1851; however, the *American System has* only been recognized as a topic in the history of technology since the 1960s.

20. This was taken up at the beginning of the 20th century. One standard element of the American approach to technology that was repeatedly mentioned and was even more striking in the 19th century than it is today was the radical nature of mechanization - the use of working machines wherever possible. This tendency was often interpreted as a logical consequence of high wages. However, if you look at real rather than nominal wages, the wage level was not so much higher everywhere than in industrialized European countries. The passion for mechanization apparently existed at times independently of economic rationality. It could not be explained by an abundance of cheap capital: The interest rate in the USA was at times even higher than in England; accordingly, in the 19th century, light, uncomplicated, not particularly solid, but cheap machines that paid for themselves quickly were considered typically American.[28] Costly technical development work - it was said there

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The new regulations - which were once in place - contradict the pace of the American economy and the urge to get rich quick.

This image, which did not apply everywhere even in the 19th century, changed radically in the second half of the 20th century: Now the USA - in the critical view of David F. Noble - has *become* the stronghold of the close alliance between *scientific technology* and *corporate capitalism*.[29] Here, the American image is remarkably similar to the former profile of German imperial industry and technology.

With the triumph of the Singer sewing machines and even more so of the Ford T-model, mass and series production was considered the most spectacular and frightening feature of the American production method for European competitors. Mass production, series production, interchangeable individual parts and mechanization to the extreme limits of what was possible became a logically coherent system at Ford - without this having been planned from the outset. From that time on, it became tempting to recognize a trend in this direction, driven by internal logic, throughout American industrial history since the beginnings of the Union and since Oliver Evans' automatic mill. This overlooked the fact that the production of interchangeable individual parts was an expensive and unprofitable business until well into the 19th century, requiring skilled manual labour and only worthwhile in the production of weapons.[30] The interchangeability of individual parts, which enabled rapid repair, had existed as an ideal since Jefferson; but its realization outside the arms industry failed for a long time due to the costs. Until the late 19th century, specialization, but not mass production, was perceived as the hallmark of American production. Rather, the constant drive for new inventions was perceived as "typically American"; however, this was in tension with the rigidity of mass production.

Both the agitation and the endeavor to make life easier for oneself with the means of

technology as convenient as possible, have been considered to be the most 19th century as an American trait. The USA led the way in the mechanization of the household, aided by the lack of service personnel and the self-confidence of American women. A high willingness to specialize in the division of labour was observed among workers and engineers, but a much lower tendency towards professionalization. The lack of skilled labor had its price. A German "Book of Inventions" from 1897 contains the observation "that the American is less demanding with regard to technical equipment and more easily ignores aesthetic and technical imperfections; he does not grumble, and that is not a bad trait". Something similar can still be observed today. Identification with a profession that is preferably a lifelong pursuit and is characterized by formal qualifications

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The German's desire to pursue a profession that has been defined as such is still considered a trait that distinguishes the German from the American, but today it seems to admirers of the USA to be an old braid that finally needs to be cut off.

From a German perspective, the wasteful use of natural resources was one of the most striking and annoying traits of the American economy. America was the country where people were always ready to buy something new quickly and scrap the old instead of maintaining and repairing it: a behavior that boosted the pace of the economy and innovation. The spread of the "throwaway mentality" in the Federal Republic of Germany also marked an important turning point in German economic and technological history. In the American 19th century, wood and water power were the most wasteful resources, not so much iron. In the USA, the wooden basis was quite compatible with mechanization and mass production to a degree that was remarkable for the 19th century. As Nathan Rosenberg has recently pointed out, the high degree of mechanization in the timber industry at the technical level of the time was associated with enormous wood waste, which could not have been afforded in Central and Western Europe at the much higher timber prices there.[31]

What general conclusions can be drawn and applied to the consideration of the "German way"? First of all, that a national technological style cannot be determined by specific technologies, but is linked to the organization of production processes and the overall way in which technology is handled. Natural resources and labor costs are among the basic conditions; nevertheless, a national technological style is not a mere function of factor costs. It has an anthropological basis: the relationship to technology becomes second nature to those who work with it and remains unaffected, at least in the short term, by price and cost fluctuations.

Mass and serial production are not the result of a technical and economic logic that is independent of space and time, but rather arise from certain conditions and a certain economic and consumer mentality. The same applies to the permanent pursuit of technical innovation. Habakkuk found that the "American willingness to scrap" was "partly irrational from an economic point of view".[32] A different kind of innovative behavior in Germany need not be interpreted as pure inertia.

The American example shows that a national technical style is subject to historical change, but that some elements nevertheless exhibit considerable tenacity. However, the phrase "American system" contains a false suggestion in that one should not think of a national technology profile as a compact whole, but rather as a

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"Problem landscape" with characteristic tensions and contrasts. The
The "American system" is the idealized, exaggerated image of a few particularly innovative industries, which by no means represent the entire economy. The American 19th century was characterized not only by the replacement of manual labour by machines, but also by a highly developed tool culture. In the 20th century, the technological profile of the USA developed a pronounced dialectic: the "American system" culminated in Henry Ford's assembly lines; but the rediscovery of manual labour and its hidden rationalization potential also took place in a sensational way with Taylorism. In the 1920s, the waste of people and raw materials provoked a backlash of safety and thrift campaigns. The 1950s initially brought the aggressive "shark" styling of cars, but then the prompt implementation of drastic speed limits. Traditional American pragmatism gave way to a focus on science in high-tech industries. German perceptions of American "hurry-up" work and of the
The "muddy" clutches of American cars, with which the unprepared driver would end up in a ditch at the first sharp bend, became a prejudice. German cars could be steered and braked more sharply, but the "big sleds" of the Americans offered more space for crumple zones. At times, a German-American contrast in automotive safety philosophies developed: German cars were dominated by active safety, American cars by passive safety. In this case, the philosophy came from the technology, not the other way around. In the end, German drivers also got their crumple zones. German development also had its own dialectic: this was partly analogous to the American one, partly in the opposite direction.

Hans-Liudger Dienel illustrates characteristic American-German differences in style by comparing developments in refrigeration technology. The differences cannot all be traced back to *one* point, but had various reasons: on the German side, the engineers' theory-driven striving for thermodynamic optimization, on the American side the preference for ice cream, ice-cooled drinks and air conditioning. "The Germans were slower, more thorough, more flexible, more expensive, more complicated, more energy-conscious. "[33] An overall picture of ideal-typical unity! These characteristics were often, but not always, an advantage. They often proved to be remarkably resilient, but were not a historical constant. German consumers also acquired a taste for American refrigeration, and the German refrigeration industry also learned to adapt to it.

Both the American and German paths were largely determined by the type of labor resources available. American machines had to rely on a frequently changing, short-term semi-skilled workforce.

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German factories preferred to cultivate a fixed workforce and a type of worker who identified with certain activities and pursued them for a lifetime. The extent to which the popular qualification of labor in Germany stemmed from a technical necessity becomes an open question when we look beyond Germany's borders.

The exemplary nature of *Swiss* industrial development has recently been emphasized by various parties, not least in the search for development models for resource-poor countries in the "Third World".[34] The Swiss model encourages consideration of how the
"German way" - characterized by chemistry, electrical industry and mechanical engineering - could have looked like without a national power state, without coal and heavy industry and without automobile production, or, conversely: in what way the
"German way" was shaped by the latter factors. Even more so than in Germany, industrial success in Switzerland had to be based on the optimal use of human labor and water power. Electricity was regarded early on as a form of energy particularly suited to Swiss conditions; at the end of the 19th century, Switzerland was the country that "every electrical engineer looks to with pleasure". In truth, the electrification of Switzerland was by no means "natural" on the basis of geographical predestination; on the contrary, despite high coal prices, steam power was still cheaper here than electrically transmitted hydroelectric power at the end of the 19th century. The initial electric euphoria was followed by a deep crisis, to which the electrical industry responded with increased propaganda. The "most sensational event of the International Electrotechnical Exhibition" in Frankfurt in 1891, the power transmission from Lauffen am Neckar to Frankfurt over a distance of 175 km, which was celebrated by Georg Siemens as a bastion of electrical engineering, was a joint venture between the Swiss company Oerlikon and AEG.[35]

Similar to the old southern German industrial centers, Swiss mechanical engineering came more from the tradition of precision mechanics than from that of steam and mining machinery. Switzerland became - largely thanks to the historically grown group culture of watchmakers in the Swiss Jura - more closely associated with the watchmaking industry than almost any other country with a specific branch of industry. Although the textile industry had been of great importance to Switzerland since the 18th century, the impetus for mechanization was slow to materialize. Until around 1780, Switzerland was even ahead of England in cotton production; in the following period, however, the Swiss textile industry was plunged into a serious crisis and a very consciously discussed decision-making situation by the English machine yarn. The solution was neither the reagrarianization of Switzerland advocated by many nor the start of a technological race with England, but rather

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specialization in niche markets.

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The focus was on quality products, where the abundant availability of cheap, skilled labor came into play compared to England. The economic rationale of this delayed mechanization - which was certainly linked to the high exploitability of labour - has recently been rediscovered[36] ; comparable discoveries can be made for early industrial German regions.

The same applies to the need to take the natural environment into account in industrial development, which has always been impressively visible in the Alps. Free-trade Switzerland, which was dependent on food imports, had to strive to process its own agricultural products into the highest possible quality foodstuffs; here the food industry became a leading sector, also in technical terms. The "cheese fever" that gripped many Swiss valleys in the 19th century brought about a technically induced transition to larger production units. However, the expansion of alpine farming, an indicator of growing export orientation, also improved the ecological stability of agriculture in the mountains. The industrialization of livestock farming was limited in the 20th century by protectionist measures in order to preserve mountain farming.

The protest against the growing tide of motorization took on particularly violent forms in Switzerland, so that the curiosity of a "car party" emerged as a counter-reaction. The construction of a large hydroelectric power plant in the Rhine forest was prevented in the 1950s by a broad-based opposition movement among the population. There was also effective opposition to the environmental sins of the chemical industry here relatively early on: with the "fluorine war" of the Aargau farmers against Alusuisse (1956 - 58). The Basel chemical industry, which discharged its wastewater into the Rhine, was itself a pioneer in shifting environmental pollution out of the country. It was only when French engineers dammed the Rhine downstream for the new Kembs hydroelectric power plant in the 1920s and the chemical wastewater sloshed back into Basel that the alarm was raised and environmental pressure to act arose for the first time.[37] All in all, precisely because Swiss industrialization runs parallel to German industrialization in many respects, it also reveals some alternatives and German peculiarities.

4. The German ideal of scientific technology and the rediscovery of experience

The thesis that the path of technological progress leads to the increasing scientificization of technology, and ultimately to the unity of science and technology, has been put forward since the 19th century, first in Germany and then in the USA.

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became commonplace in other countries too. It was this link between technology and the human thirst for knowledge that gave rise to the conviction that technological progress was infinite. Sombart proclaimed that "modern technology", just like natural science, was the "true child of the revolutionary, Faustian, European spirit"; both were "simply one", "their course of development" was "the same"; and since science was constantly advancing, one could "speak of an inherent (immanent) tendency in scientifically based technology towards a boundless and almost automatic expansion of technical knowledge".[38]

This credo has been repeated countless times since then and was considered progressive until the 1970s. The path to the "scientific-technical revolution" - often abbreviated to "WTR" - became a law of history in Marxism-Leninism of the post-Stalin era. However, German technical universities also teach that the old relationship between theory and practice - namely that technological theory followed technical practice - has been "definitively turned on its head" in modern technology: theory is taking the lead in "ever larger areas" to such an extent that "the transition from research machine to production machine is becoming fluid" - "for example in nuclear research machines and nuclear power plants". This means nothing less than "a new great epoch in world history". "The hopes of the future rest on the 'science-based industries'. "[39] More than anything else, the genesis of nuclear technology from nuclear physics gave rise to this belief. Since then, the history of technology has often been regarded as a branch of the higher-ranking history of science.

Progress through scientificization: This view of history and the future is of central importance for the interpretation of German technological history, because according to a view that is also generally accepted abroad, Germany played a pioneering role in the scientificization of technology. The "essence and global success" of "German technology" rested on its "scientific attitude": this was emphasized in the late
In the 19th century, it became a ritualistically repeated creed, above all of German chemistry and electrical engineering and of the technical universities that demanded academic honors.[40] This credo was certainly not plucked out of thin air; nevertheless, it is worth taking a closer look at what
"scientification" of technology and the interests behind this invocation of science.

Brady recognized a *curiously Germanic aspect* in the striving for the scientification of all economic life: "It is science that gives at once its most perfect and most fruitful expression to the notorious German tendency to order, arrangement and system." An examination of the thesis of the German path to scientific technology is

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This is all the more necessary as it is not an all-encompassing and logically compelling trend in the history of technology. If modern technology makes use of scientific methods and parts of the natural sciences justify their worthiness of promotion on the basis of technical benefits, this affinity must not distract from the fact that knowledge and product development are different things and, properly pursued, follow different laws. Hausen and Rürup rightly note that the common definition of technology as an applied science, which "for a long time was not problematized at all, was a burden on the development of the history of technology".[41] If technology was misunderstood as a cognitive system, the historicity of technology was misjudged, as was its function in the economy and everyday culture.

Even in the case of nuclear technology, which was once regarded as the pinnacle of the fusion of theory and large-scale technology, nothing is more misleading than the idea of a smooth transition "from research machine to production machine"; this misconception was one of the fatal illusions in the history of nuclear technology. In the 1980s, however, a new naivety flourished in the expectations placed on research. Following the American model, there was a boom in the founding of "technology centers" and
"A few years later, disillusionment spread as the industrial effect of this zeal was hardly noticeable - an experience that seems to be repeated from time to time.

There was a seamless transition from theory to technology, especially in the armaments of war. The theoretical optimum, unaffected by cost and benefit considerations, frictional losses and human factors, came into play above all where the aim was not to serve mankind but to destroy people. From Galileo to Oppenheimer, the pure form of mathematical-physical processes could be studied particularly well on bombs (even if Galileo could hardly have made even a single cannon shot more precise). As a result of the world wars of the 20th century, the scientification of technology became an international trend. The belief in progress towards the identity of technology and science was increasingly combined with the idea that armaments were the strongest driver of technical progress.

In the technological literature of the 19th century, "science" is often pitted against "empiricism". However, this confrontation, driven by the engineer's quest for prestige and academic professionalization, was ultimately just a battle of mirrors, as industrial technology could not seriously believe that empiricism could be dispensed with in the long term and that everything could be based on theory. Technology was only constituted as a discipline in its own right vis-à-vis mathematics and physics through empirical methods.

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ured. It was not only about the experience that could be reproduced experimentally in the laboratory, but also about the personal experience gained in practice and related to a specific environment. This practical knowledge goes beyond the technical field in the narrower sense. As understood, "technology" encompasses "types of knowledge that are entirely social, political and cultural in nature" (Burns/Ueberhorst).

Terms such as "experience", "know-how" and "tacit knowledge" refer to a phenomenon that is encountered at every turn in the history of technology. This applies in a special sense to large-scale technology: to the construction and operation of large and complex plants, where long-term material properties, difficult-to-understand interactions between the multitude of components and also very rare, initially more hypothetical failure possibilities come into play and where optimization no longer has to do with a few basic ideas, but with a long stream of detailed and improvement innovations. In a different way, however, this also applies to technically complex consumer goods, whether cars, washing machines or PCs: these could only become mass products through a long-lasting interplay of technical development and consumer experience. In this respect, the importance of experience has actually increased over the course of recent technological history. The required experience has become more extensive; it extends over historical periods of time; spontaneous memory is no longer sufficient to transport this experience.[42] The role of historical reconstruction is all the more important because the most valuable experience often arises from failures, but precisely this negative experience, if it is not deliberately brought to light, usually remains a personal memory of those affected, reluctantly brought to public attention: a circumstance which, if not consciously counteracted, results in a "very insidious form of historical falsification" (Crombie).[43]

Experience is repeatedly incorporated into theories and doctrines and is
The process of industrialization seems to be suspended in these; nevertheless, it is a never-ending process in the history of technology. This seems to be a banality; nevertheless, the significance of this fact had to be rediscovered several times in industrial history. Until the second half of the 19th century, the decisive importance of experience was still taken for granted in leading technological sectors such as mining and metallurgy, metallurgy and steam engine construction; a reliable theoretical basis existed in fragments at best. Even in the 20th century, smelting technology was still determined by the local ore quality.[44] But since the late 19th century, the self-confidence of technological theory grew in Germany. It is precisely the superiority of experience in practice that may explain the vehemence of some attacks on empiricism. The pathos of scienti

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The statement contained the confidence that sooner or later all experience would be replaced by theoretical deduction, if not already.

This overestimation of theory could not be sustained in the long term, neither in the production of consumer goods nor in large-scale mechanical engineering. The rediscovery of the intrinsic right of experience was sometimes striking among German technicians. In 1941, the power plant constructor Münzinger emphasized experience as the soul of engineering and "one of the strongest foundations of technology". For the experienced engineer, direct observation often led further "than any theory or calculation". Only experience gives a sense of where to pause in the pursuit of maximizing thermal efficiency because the machines threaten to become too complicated. After four decades of engineering experience in large bridge construction, Fritz Leonhardt criticizes the "faith in highly scientific theories" that forgets that the "rough practice" does not match the "idealized assumptions" of the calculation models, and reminds us in the age of computer simulations: "We engineers learn primarily from our failures. "[45] The essence of experience lies particularly in the unpleasant surprises.

If respect for experience also led to the appreciation of non-formal qualifications acquired through long practice, then it would have made sense to consult not only engineers but also workers and craftsmen when making technical decisions. However, this consequence, which contradicted the professional interests of the engineers, was not readily accepted. In 1898, a Siemens director objected to a passage in a new draft of the company's service regulations which stated that "suggestions for improvements or proposals for [...] innovations would be gladly accepted from all employees": There were already too many such suggestions anyway, he said, most of which were useless and only made additional work. The paragraph was deleted: a significant event at a time when engineers in the new industries had the ambition to break the "master rule".[46]

However, the empirical knowledge of local practitioners was never permanently devalued, but rather its temporary devaluation was repeatedly recognized as a mistake. This even applies to the "scientific" industries. When Carl Bosch was asked by American journalists in 1923, during the Ruhr War, whether the French could run the Ludwigshafen factories on their own without German help, he responded: "Without the German workers and plant managers, the factories would be worth no more to the French than a pile of bricks. "[47] At the sight of the ruins after 1945, the realization at Siemens that it was not things but accumulated experience that mattered became the basis for a new confidence.[48] Later, under the sign of the "new tech

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nologies", "know-how" became the magic word. "Experience" is "the key to almost every sector" of electronics, Japan assures us, which is why "the continuity of personnel is of the utmost importance". New production concepts based on electronics in the Federal Republic are based on the premise that "know-how and experience are not recognized as an annoying resource, but as an indispensable part of the development of productive power". The disregard for employee inventions and technical suggestions from practice, which stems from the tradition of scientification, is seen as an obstacle.[49]

Since experience is bound to space and time, to direct observation, personal networks and personal transmission, the basis of technological experience sheds new light on the significance of regional and national continuities for technological development. At the same time, the question of breaks in continuity and the accumulability of experience arises. The difference of opinion as to whether the nuclear power plant operators actually have, as they claim, the "wealth of experience of more than a hundred years of high-pressure steam technology" and, by adding reactor operating years, even over a thousand years of experience, or whether nuclear technology actually has very little experience and even less experience that has been understood and made usable, can be seen as the core of the nuclear conflict, as can the question of whether and how a replacement for a lack of experience can be found. [50]

5. Rationalization, system compulsion and compulsion to greatness: the "tyrannical element" in technology

Even if technology is not an applied natural science, technology and natural science could both be understood as core elements of the modern rationalization process and thus be linked with each other. From this it could be concluded that the search for regional moments in the history of technology only leads to peripheral aspects and distracts from the main issue.

Those who make "rationalization" the acting subject of "modernization" prefer to refer to Max Weber. However, in a later revision of his *Protestant Ethics,* he explained to ward off misunderstandings: "If anything, this essay would like to contribute to uncovering the ambiguity of the only seemingly unambiguous concept of 'rationalization'." "Rationalization" is not an unambiguous concept at all. Its weakest point is the indeterminacy of the goal that makes it possible,

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even Auschwitz and Hiroshima as phenomena of rationalization, since methods of mass production and *economies of scale* were applied to the killing of human beings. In this context, "rationalization" still seems to have a methodical and technical unambiguity: as a way of achieving predetermined goals as quickly, smoothly and completely as possible with maximum efficiency of means. But even the technically defined concept of rationalization becomes ambiguous in concrete technology. Maximizing efficiency can lead to expensive, overcomplicated systems that are prone to failure, increasing speed can lead to human wear and tear and a waste of resources, and mass production can lead to susceptibility to crises. If you optimize a technology from a certain point of view, you usually come into conflict with what is optimal from other points of view. From a purely technical point of view, in many cases there are a number of "optimal" solutions. However, since technicians tend to be guided by their respective experiences and do not consider all aspects in the same way, the illusion of technical constraints and *one* solution often arises.[51] In typical cases, technical rationalization comes into tension with the long-term advantageous use of the human production factor. A considerable part of the history of rationalization in the 20th century can be described as a dialectic between the pursuit of perfection in technology and the rediscovery of the neglected human factor.

The trend towards networked *systems is* subject to comparable tensions in the history of technology. In fact, for centuries there has been a tendency towards the development of interrelationships, dependencies and networks between different technical devices. A typical pattern of the innovation process is that innovations initially only relate to individual machines or components, but over time trigger chain reactions and ultimately bring about a new phase in which the fundamental innovation no longer consists of technical details, but rather of improving the overall context. However, this dynamic is not necessarily deterministic. In many cases, the networking of individual elements was only of a loose nature, and the remaining leeway did not represent a shortcoming, but rather an elasticity of the system. The partial mechanization of individual work processes did not necessarily lead to the mechanization of the remaining production stages: Manual labor and mechanized production could coexist for a very long time.[52]

As Lewis Mumford showed, the human "megamachine" - the centrally controlled system of domination - existed long before the steel machines were built. The ideal of full automation, of the factory functioning like a large clockwork mechanism, was already present in early industrialization, indeed was already being passed off as a reality: According to Andrew Ure

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The main point of Arkwright's "Herculean undertaking" was not to invent self-acting machines, but to combine the "various links of the apparatus" into "a single cooperative body" and, above all, to get people to "identify with the immutable regularity of the complex automaton". Even the dream of getting rid of recalcitrant workers through automation is already haunting the imagination of early industrial technology entrepreneurs.

In reality, however, the vast majority of 19th century factories were anything but smoothly functioning automatons. Akos Paulinyi has pointed out that the term *automation* "describes different things in different eras": "For the person who was used to watching the sweaty lathe operator holding and guiding the turning steel, the same production process on a lead or draw spindle lathe was automatic." When "automation" became a fashionable topic in the late 1950s, it was necessary to reconstruct what was actually meant by it (which often remained unclear). In many cases, the fully automated factory remained a pipe dream right up to recent times, driven not only by economic and technical opportunities, but at least as much by the mechanistic dream of power stemming from the early modern era. The possibilities of computerization were almost misunderstood when computers were seen not as components but as generators of a perfectly automated system.[53]

The "system" in the ideal sense would have to have perfect learning, feedback and reproduction mechanisms. Last but not least, it would have to be capable of reacting adequately to its environment. Understood in this way, "systems" in the full sense only exist in the organic and social world, not in technology. The trend towards systems that can be empirically observed in the history of technology - the increase in complexity, interdependence and networking - can even significantly reduce the ability to react flexibly to changing external conditions. At some point, this becomes noticeable as a crisis; the trend towards the internal perfection of a system is replaced over time by counter-trends. A discrepancy arises between the ideal-typical system and the factual interlocking of processes.

The real systems are usually in flux, are bound to time and society and do not reflect abstract rationality. Factories that had been "rationalized" around 1900 could have become a labyrinth again a few decades later as a result of production changes brought about by the changing times. The transportation system, which at times progressed towards a closed system with the expansion of the railroads, became a flexible chaos in the 20th century. Although engineers were increasingly able to design automobiles as integral systems, the motorized transport system became a flexible chaos.

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They could not get to grips with the overall system. It is therefore by no means logical to assume that the systemic trend in many individual areas of production and technology application will inevitably lead to a large overall system, to the "scientific civilization" once claimed by Schelsky, which can no longer be explained by history, but by the logic of technology. History itself has long since thoroughly refuted this thesis. If one assumes that a high degree of internal networking of systems increases rigidity in relation to the environment, then it follows that the trend towards a system, viewed from the perspective of society as a whole, is a source of tension. System rationality does not lead out of history, but contributes to the historical dynamics of technology. In the light of empiricism, one must critically ask whether the alleged "systems" actually exist in reality as they are designed in the model.[54]

Bureaucratization in government and industry often took place in historical proximity to technical developments. Again, one could construct a technical constraint and turn affinity into causality: A more complex technology requires a more complex organization, especially when the technology does not have its system perfection in itself, but only gains it in conjunction with organization. The need to separate planning and execution and the emergence of planning offices can also be derived from this growing complexity. Highly complex technology also changes human thought structures: it accustoms people to seeking solutions to problems by "technical" means, through certain procedures based on the division of labour with specific rules and role assignments, and to organizing human cooperation as an "apparatus".

Again, however, it is questionable to what extent all of this is a matter of technical logic. In technology, there is by no means only a trend towards the large and complex. The simple, light, robust, easy-to-use mechanism corresponds at least as much to the ideal of the technical practitioner today as it did 200 years ago. This is even more true when you consider not only production technology, but also product technology. Not only the power station, but also the bicycle marks the progress of technology around 1900; seen globally, the bicycle is probably the most important means of transportation today. Just an isolated case? But it is precisely in the era of mass consumption that the miniaturization of products and the simplification of their handling is becoming the characteristic new technology trend. Knut Bor- chardt rightly warns against the "operational blindness of the engineering historian", which makes "complication the measure of significance".[55]

Furthermore, the separation of planning and execution is not technically conceived, but has something contradictory about it purely in terms of technical logic, because practical experience is a source of technical insight.

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Untouched by Taylorist programming ambitions, Max Eyth mocked the strict separation of mental and manual labor as a fellah manner unusual in Europe and described the comedy of the constant coexistence of one who works and another who commands him. The absurdity of this type of division of labor has recently been rediscovered.[56]

The affinity between technology and bureaucracy does not correspond to a general system logic, but rather to nationally specific conditions. Especially in the search for the "German way", the interrelationship between technological innovations and bureaucratization tendencies - in the state as well as in large-scale industry - is one of the leitmotifs. Where technology tends to become a system and becomes intertwined with bureaucratic organization, it is particularly clearly shaped by the history of the respective society: quite contrary to Schelsky's thesis that mechanization, which has become a large system, cancels out history.

Adjacent to the thesis of growing complexity is the theory of *economies of scale*: the view that there is a partially technically determined law of growth in size. In key sectors of German industry and technology, the trend towards growth in size is indeed a central and epoch-making element. It can be derived from the tendency of some technologies to become systems, but also from basic physical and technical facts: The geometric fact that as cylinders increase in size, the volume increases more rapidly than the total external surface area leads to a degression in costs for both blast furnaces and pipelines as the size increases. One argument for the technical logic of the increase in size, but not of general physical validity, was the advantages of the compound system in the use of waste heat and residual materials and was also the rule of experience, valid until the computer age, that special machines achieve a higher efficiency than multi-purpose machines.

The advantages of size were simple and suggestive; they did not fail to have an impact on economists and technology historians alike. The contrary facts were often more complex; they had to do with the loss of flexibility with high fixed costs, the material problems and residual risks of large-scale technology and the reserve capacities required for the failure of large-scale plants. It was often only historical experience that made the limits of the advantages of growth in size clear.[57] The course of events in Germany shows that the growth in size that resulted from the expansion of the market in the USA only came about here in part as a reaction to the American model and was strongly influenced by political factors and the two world wars.

For Otto Ullrich, industrial capitalism results in an immanent-logical development of technology towards a "reified block structure" - towards a

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The logic of the large-scale system, sealed off from people and the environment, is based not only on an identity between the logic of technology and that of capital, but also on an essential similarity between modern technology and science; in the case of science, he assumes or suspects a systemic compulsion towards growth in size, towards *Big Science*.[58] But the benefits of large-scale scientific and technological projects for a market-oriented industry are questionable; there can be no question of a general law. Even from a pro-nuclear perspective, the large-scale projects of the nuclear research centers ultimately only harmed the development of nuclear energy; their true benefit was of a bureaucratic nature and consisted in the fact that they established the scientific competence of the federal government.

Piore and Sabel's cheerful historical panorama is quite different from Otto Ullrich's diagnosis. Here, the alternative to *economies of scale* is not an eco-socialist utopia, but has long been a historical reality: in the ever new market-induced trend towards adapting production to individual and changing needs, and in the continued existence and resurgence of small artisanal businesses, of which some German regions - such as the Bergisches Land with its ribbon weaving and small iron industry - are prime examples. In this view, mass production does not arise from a general economic or technical logic, but rather from historically specific conditions: the influence of armaments and war, industrial concentration and the state's preference for size, as well as the suggestive power and displacement effect of Ford's example and other role models.

In fact, the specific techniques of mass production - combination of special machines, series production, interchangeable individual parts - appeared earliest in the armaments industry. The conditions under which mass production emerged in wartime and post-war times and also the limits of mass production can be exemplified by German history. However, mass production and flexible specialization were not sharp alternatives over time; the famous example of Ford's T-model is historically limited in its model value.[59] Especially when American methods of mass production were adapted to the more limited German market, greater flexibility had to be ensured. To this day, parts of German industry are characterized by an uneasy balance between standardized mass production and flexible specialization. The German path in technology is a story without end.

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6. Anthropological criteria in the periodization of the history of technology

When technology constitutes experience, it becomes part of the people who handle it. Habitualization, habituation, internalization - the processes that cause certain mechanical processes to "become second nature" to those who operate them - are a fundamental process in the human relationship to technology. Human sensory perceptions, thought structures, experiences of pleasure and communicative behavior are shaped and changed by the use of technology. Attitudes towards certain technologies are changed by becoming accustomed to them. Repetitive partial work is perceived quite differently by former craftsmen than by workers who know nothing else. The working world of the Solingen grinders, who for a long time tenaciously defended their autonomy against mechanization, had a repulsive effect on metalworkers who had become accustomed to the factory and also to a certain degree of hygiene. It is not only today that the experience is sometimes made that a "job enrichment" oriented towards the old manual ideal of variety is not at all desired by workers who have become accustomed to the rhythm of monotony.[60] The rapid expansion of screens since the 1980s represents at least as much an anthropological as a technological caesura.

The development of production technology causes alienation, causes

However, adaptation effects also occur over time. An intimate relationship between humans and technology develops with devices that are controlled by their users and react to their impulses. The massive spread of the bicycle, motorcycle and car marked a milestone in the human relationship with technology, especially from the time when "technical socialization" began in adolescence. When many people learned to "feel with the engines" from a young age, a new era in the historical anthropology of technology began. Currently, computerization is creating sharp generational divides among industrial workers, which are projected into the technology itself: In "new technologies" in particular, there is often exaggerated talk of "generations". Home computers, which make some kind of communication possible, also visibly mark a new phase which - as mathematician Ernst Schuberth warns - could lead to social conflicts increasingly being perceived as "program errors" and addressed by attempting to reprogram fellow human beings.[61]

The vending machines began - historically speaking - as a gimmick. The riser

Increasing speed is first and foremost a sporting ambition, not an economic one per se. In many cases, new technology is not simply a response to a need for speed.

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rather, corresponding needs for technical artifacts develop. The element of playfulness, coincidence and purposelessness in the history of so many inventions is not merely a marginal phenomenon; it sometimes leads more to the heart of the matter than the weighty justifications used to emphasize the public utility of a technology. From the best tinkerers of old to modern computer freaks: many phenomena in the history of technology up to the present day do not fit the ideal of *homo oeconomicus*, but rather an image of man in which the play instinct, the desire to show off and agonal passion run riot without always being about clear economic advantages. To understand the history of technology, not only economic, but also ethnological and ethological approaches are useful.

The philosopher of technology Dessauer rightly emphasized that there is "an obsession with technology that goes as far as martyrdom". This obsession reached a new peak among computer programmers; it has a long history. Popular technical literature has repeatedly emphasized the element of play and passion in the history of technology - in curious discrepancy to the technological determinism frequently encountered there. "Man is an incorrigible play rat", began an editorial article in *Prometheus* in 1912.[62] The mechanical clock, the prototype of the automaton that was unrivaled by other technology for centuries, was not created as an instrument for measuring time precisely and as a response to everyday needs, but as a showpiece of symbolic significance, as a demonstration of an artfully perfected order: at a time when sundials were even more precise. Today, as Günter Ropohl notes, home computers are much more often used for video games than for "budget and tax calculations".[63]

Gender-specific mentalities developed to a large extent in the use of technology. As was already recognized in the early 19th century[64] , modern technology predominantly had the effect of expanding the area of male competence. It is true that the *Communist Manifesto* of 1848 already believed to recognize a contrary law: "The less manual work requires skill and strength, i.e. the more modern industry develops, the more men's work is displaced by that of women and children." But this applied primarily to the textile industry, which Friedrich Engels had in mind. In other sectors of early and high industrialization, a new, often technology-specific type of male habitus, male pride and masculine body experience developed around tools and machines. It is reasonable to assume that the connection between technology and masculinity had an impact on the course of technical development and contributed to a "hard" image of technical progress. The

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The rise of technology in the 19th century clearly converged with the evolution of gender roles and the revival of patriarchal structures.[65] Industrial technology and compulsory military service worked together as courage and martial prowess, once the pride of the knight, became bourgeois virtues.

From the end of the 19th century onwards, however, the innovative directions of technology were no longer so clearly masculine, even if the bicycle, sewing machine and typewriter were not celebrated as the self-acting promoters of female emancipation in the sometimes popular way. While physical strength and manual skills, which had previously been the domain of men, retained their importance in many cases during the early stages of mechanization, the trend towards the devaluation of qualities traditionally considered masculine intensified in the 20th century. Physical strength became less and less important; the

In the rationalized factories, the "male" work rhythm of strong muscle tension and rest breaks was replaced by a work flow that followed more the traditional pattern of female work, the "tireless" location-bound activity. If women's disadvantage persisted, it had less and less the appearance of technical rationality.

Nevertheless, it would be wrong to expect technical development as such to lead to gender equality in the production process. Even today, computer freaks are still predominantly male. The search for a direct causal link between technology and working conditions has proven to be a mistake.[66] The habits of work and work organization have a tenacious life of their own that outlasts many a technical change. The division of labour originated as a pre-industrial principle corresponding to manual labour; nevertheless, despite predictions to the contrary, it has expanded into wide areas of production in the course of industrialization. There are indeed intimate connections between the history of technology and the history of work, but as a rule they do not take the form of a prompt sequence of cause and effect, but rather consist of long-term processes of mutual adaptation of work traditions and new technology.

The search for a direct lawful connection between the history of technology and the development of qualifications has also remained without a universally valid result. From the beginnings of industrialization to the present day, there has been the higher qualification thesis and the dequalification thesis. While some asserted that machines were relieving people of tedious and monotonous work and allowing them to concentrate more and more on the actual human, intellectual work, others argued that machines were increasingly acquiring human skills, making people less and less capable of doing the work.

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The company has degraded people to cogs in the machine and replaced the self-determined human rhythm of work with machine rhythms.

Both arguments contain only partial truths. It is highly unlikely that there is a single major trend towards upskilling or downskilling. At best, a uniform impression emerges when one looks at certain key sectors. For example, the widespread picture is that mechanization initially led to deskilling in the 19th century, under the dominance of the textile industry, whereas from the end of the 19th century, mechanization led to upskilling.

It is doubtful, however, whether the de-skilling and disciplining of workers that was the aim of the early textile machines actually succeeded in general.[68] On the other hand, parts of the mechanical engineering and, above all, the automotive industry drove the division of labor in series production to the extreme. The picture also remains incomplete if one focuses on certain particularly technically advanced sectors - on the assumption that these embodied the future - and overlooks the areas in the shadows, including homework, part-time and unskilled labor. Thirty or 40 years ago, when Fordist ideas about the future of work were still prevalent in Germany, deskilling was often seen as the dominant trend. More recently, however, growing unemployment is attributed to the fact that the modern economy no longer needs poorly qualified workers, but neglects the qualification of labor.

A fundamental dilemma in all attempts to answer the question of the impact of technological change on qualifications stems from the ambiguity of the concept of qualification.[69] There is usually a wide gap between the qualification formally prescribed for an occupation and the skills required in practice. This is particularly important in Germany, where formal qualifications are traditionally accorded a high value. By examining specific work processes, the history of technology in particular can call into question overly simplistic distinctions between "qualified" and "unqualified" activities and reveal the lack of a technical basis for formal qualification requirements. Was the manual dexterity of the poor needle grinders really so much lower than that of the respected sword makers; was the preparation and spinning of flax fiber technically so much easier than the highly respected work of the printer?[70] Long periods of apprenticeship can - as the critics of the guild system in the 18th century already complained - be of little practical use; in contrast, unskilled or "semi-skilled" work can require a great deal of experience or be considerably improved by experience. Whether a job is considered "skilled" depends not only on the skills required, but also on the assertiveness of the worker.

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The skills required depend on the respective occupational group.[71] Activities that belong to the basic skills of many women are usually considered unqualified.

If we try to combine the history of technology with a history of work, we realize how inadequate it is to measure the quality of work using only the concept of qualification. The experience of work, the sensual content of work and the self-awareness conveyed by work must also be brought to life in order for work to gain historical contu- rence. A technically induced change has taken place precisely in the anthropological qualities of work.[72] This leads not least to the importance of materials as "guiding fossils" of periodization: wood as a material was associated with a certain sensitivity of the hand and a polytechnical culture of manual work. Later, the educational value of iron for skilled workers was often invoked: "Iron educates." Today, when looking at computer screens, it is common to discover the extent to which the industrial technology of the 19th and early 20th centuries possessed something vivid and physical. Not only for the engineer, but also for the worker, technology contained offers of identification, and this in increasing abundance.

Even pre-industrial craftsmen had strived to define their trade identity through their tools and materials - as can be seen from the pictorial decoration of guild chests, but also from border disputes with neighboring trades. Carpenters, joiners, turners and woodworkers could only succeed in this inadequately.[73] But what were these tools and materials compared to modern machines and special steels! The chance of finding the identity of work in the things one deals with was considerably increased in the industrial age until well into the 20th century. In this respect, the idea that the machine levels the workers is obviously fundamentally wrong and merely reflects the prejudice of educated citizens; it has been impressively refuted both for early industrialization and for more recent times.[74]

The technology of work and the skills developed in the process shape the consciousness not only of the "old crafts" and skilled craftsmen of the 19th century, but also of modern industrial workers to a large extent: Oral history has reminded us of this.[75] Is it a class consciousness that this creates? Hendrik de Man, who described the skilled worker's "joy of work" in warm colors even in the era of "rationalization", nevertheless emphasized that the "feeling of solidarity that underlies the idea of organization and class struggle" was "not a product of the technical work experience"; it was formed "in the assembly, not in the company".[76] Most historians of the labour movement also seem to assume this, as they deal far more with assemblies and organizations than with workplace experiences.

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And yet the impulse contained in Marx's theory to derive workers' consciousness from the production process should not be dismissed out of hand. Even if not necessarily the proclaimed class solidarity, the empirically observable workers' consciousness clearly has something to do with production conditions. Certainly, the consciousness arising from the technical experience of work could not be anything other than heterogeneous and partly contradictory. Alienation and self-consciousness through mechanized work existed side by side. One can recognize in this the emotional correlate to the ambivalent significance of technology in socialist ideology: technology as the objectified alienated work, but ultimately also the great power of emancipatory progress.

Until a generation ago, the activity of the worker remained predominantly manual work: therein lay an anthropological unity of the working class - a simple fact that was not sufficiently appreciated for a long time under the suggestion of exaggerated ideas of automation and only becomes visible in its full extent in the sight of screen work. Manual labor did not distinguish the manual worker from the craftsman, but it did from the white-collar worker; in this respect, the togetherness of the workforce in the early 20th century became even more striking at times due to the sharp increase in white-collar workers. Seen against this background, the computerization processes of recent times represent a profound break. Although it is often asserted that highly complicated, electronically controlled machines have created a new need for skilled workers, what "skilled worker" means - not only in terms of training and wages, but also in terms of actual activity - is currently undergoing a change like never before in the history of industrialization. Today's history of technology not only brings up historical analogies, but also gives at least as much of an idea of the deep rupture in the working world of recent times, which is still largely in the blind spot of historians' optics.[7]

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II. Technology for the maximum use of regenerative resources (18th and early 19th century)

1. The "wooden age" as a historical unit

When Fernand Braudel once strolled through the Deutsches Museum, he was particularly amazed by the highly developed wooden machines and mechanisms: until then, he had associated technical progress far too closely with iron and steel. The "wooden age" becomes a visual entity in technology museums; and this sensory impression has something to say. The conventional concept of the Industrial Revolution, which was revived in economic history with the technical metaphor of take-off, has proven to be inadequate, if not misleading, for the history of technology. It favoured the conventional, mechanistic, monocausal image of events, in which the steam boiler and the spinning jenny were the father and mother of industrialization, as it were, and distracted from the fact that the early days of industrialization were carried by a broad stream of innovations, some of which still require research, that continued pre-industrial techniques.[1] It was tempting to impose the English model of industrialization - and even this in a simplified, picture-book form - on the processes in other countries, instead of drawing attention to whether there were other ways of industrialization that were exemplary in their own way.

The early German industrial regions, almost all of which coincided with pre-industrial commercial landscapes, still used the "industrial landscape" until the middle of the 20th century.

In the 19th century, hydroelectric power and wood, and charcoal in blast furnaces, were the main fuels. In terms of environmental history, the transition to fossil, non-renewable fuels marked a profound turning point. The full extent of this epochal turning point can only be recognized in retrospect; nevertheless, it was accompanied by many changes that were already noticeable to contemporaries. The history of technology can be periodized in terms of the relationship between man and the environment, and not only from a modern retrospective.

It would certainly be a violation of concrete history if the entire period from the Stone Age to the early 19th century were to be subsumed under the aspect of "regenerative resources". Som- bart has occasionally used the term

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"wooden age" as a term to describe a period in history.

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The "wooden age" was played out as a characteristic of the entire pre-modern period and the decline of this era was recognized in the 18th century as a consequence of the scarcity of wood. However, it makes more sense to date the "wooden age" precisely to the period in which wood became scarcer, the wood-bound nature of the economy became a fundamental problem in the consciousness of contemporaries and technical trends were shaped by the "economic" use of wood. This was first the case in large parts of Central Europe in the 16th century and then increasingly in the 18th and early 19th centuries. In almost all German regions, wood shortages and wood-saving measures were introduced in the
This became a major issue in the 18th century, although timber resources varied greatly from landscape to landscape. Germany was a major region of the "wooden age", not necessarily in terms of natural resources, but in terms of the perception of the problem, and from the late 18th century there was also an increased search for technical solutions to problems. At that time, there was a wood-oriented awareness of the times: The modern age of wood scarcity was distinguished from the "old age of wood abundance". In 1848, when several Black Forest communities called for the abolition of clear-cutting and the reintroduction of the (highly valued by modern ecologists)
"Femelwirtschaft", the harvesting of individual logs according to demand, the Baden Chief Forestry Councillor Arnsperger rejected the petition: "Femelwirtschaft belongs to a time that we have long since left behind, a time when we still had an abundance of forest and wood, and when you could cut as much as you liked. "[2] Modernity, the era of "economy", under the sign of wood scarcity: whereby alleged counter-strategies sometimes exacerbated this!

In those days, water power was also used to the utmost in heavy areas. The companies that worked with waterwheels would walk upstream along the streams until the natural limit was reached and the last meter or even centimeter of the gradient was occupied with water rights. Around 1800, a poem in Schwelm celebrated the combination of hammer mill and bleaching plant as the maximum use of the precious water: "Not a drop of water may flow unused/What does not drive the hammer must water our yarn." The rapidly growing demand for potash in early chemistry led to the use of previously inaccessible forests from which the tree trunks could not be transported using pre-modern technology. The scarcity of wood and water power resources resulted in a trend towards decentralization, which counteracted the tendency to concentrate industry in the cities that had existed since the late Middle Ages and encouraged a shift of industrial expansion to the countryside. Since the 1970s, this era of "proto-industrialization" has been understood as a period of its own kind, but not yet in terms of its resource-related nature. The advantage of decentralization

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could lead to forms of division of labor among the wood- and hydropower-dependent trades that promoted the rise of publishing.

Wood and water power - wood also as a material - were the hallmarks of the entire technical equipment and working methods; and the more economic life reached the limits of these resources, the more clearly the endeavor to make better use of these "natural treasures" played a role in technical innovations. In many areas, early industrialization should not be seen as the end of the "wooden age", but rather as the high point of the culture of manual labour based on wood as a material; this applies not only to Central Europe, but also to Western Europe and even more so to North America. This period should not be interpreted as an imperfect prelude to the industrial boom that began in the middle of the 19th century, but rather as a different path of industrialization with its own rationality, one that was certainly promising for the future: a path whose dynamics did not stem from a growing heavy industry, but from the pursuit of reducing the proportion of energy costs and increasing the proportion of labour and finishing in the product value - a highly promising endeavour from today's perspective![3]

If Landes considers it "clear" that the willingness to use hard coal was an "indicator of a deeper rationality", this rationality must be countered by the rationality of the "wooden age". In many regions of Central and Western Europe, hard coal did not gain acceptance so hesitantly because there were deep prejudices against it, but simply because it was not yet needed. "Where water power is available, this engine deserves to be preferred to any other," wrote Ferdinand Redtenbacher, one of the founders of the science of mechanical engineering in Germany, as late as 1852 - against the backdrop of regions in southern Germany far removed from coal; "it is the cheapest of all engines, because this motor substance as such costs nothing at all, and the buildings and equipment required to use the water power never cost more, and as a rule even much less than those caused by steam power and animals".[4]

Wood and water power - but even more so the craftsmanship traditions of the inhabitants - were the natural locational advantages of the metal industry in the Bergisches Land, and although water power became scarce, it retained its importance there until the late 19th century. In the other earliest German industrial region, the Kingdom of Saxony, "good wages, low timber prices and abundant water power were the main conditions for manufacturing at the time". The same applied to the industrial centers of southern Germany and the Styrian mining region. As a material, wood even conquered a still growing variety of application areas in the early industrialization. Ernst Alban surprised "man

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The "mechanic" with his wooden lining for the steam engine; he recommended wood because it was cheaper, lighter in weight and easier to work with than iron. There was not only progress from wood to metal, but also from metal to wood.[5]

As early as the late 18th century, the vision of continuous economic growth flashed up; the imagination of some publicists anticipated the coming industrialization. In the "wooden age", however, growth prospects were accompanied by a fierce fear of wood shortages. The dispute over water was also exacerbated by the increase in industry. In the long run, industrial growth was only bearable if it took a direction independent of wood and water power. In prosperous, densely populated and industrialized regions, large-scale wood consumers such as glass and ironworks were generally pushed to the margins. As early as 1460, Nuremberg relocated the wood-eating Saiger smelters, which separated copper from silver, to the Thuringian Forest; following in the footsteps of wood, Nuremberg capital penetrated the Saxon Ore Mountains. In the 16th century, the council banned charcoal burners from the imperial forest. To secure the supply of wood, the growth of the metal industry in the city was limited.[6]

The law of decentralization also placed limits on technological development. A technological trend towards greater scale could only develop to a limited extent, even though early industrialization opened up considerable scope in this respect. However, decentralization also promoted the division of labour between towns and regions and in this way contributed to technical specialization.[7] While the "forest forges" originally combined mining and smelting works with iron processing, the smelters were subsequently separated from the mines, the hammer mills from the smelters, and the fine hammers from the rough hammers. The division of labor that developed in the early modern period in the iron industry advancing northwards from the Siegerland had led to the product becoming all the finer the further north you went by 1800.[8]

Ironworks and other metal smelters, salt works and glassworks - the largest commercial wood consumers - were scattered across large parts of Central Europe until the 19th century. However, there was not only a trend towards decentralization, but also counter-movements: the concentration of individual industries in certain regions and the formation of conurbations. The strongest force for centralization came from the residences - sometimes even against the wishes of the sovereigns: It is no wonder that complaints about "wood shortages" became more frequent there. It was precisely there, however, that they had the means to use the argument of timber shortage to establish official control of the timber industry.

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Pre-industrial and early industrial technology was closely tied to the experience of certain regions and the working traditions of certain groups of people; this also worked against diffusion. In particular, trades that required a relatively high level of technical skill and were entirely export-oriented tended to "form territories". In the textiles sector in particular, regular "territories" were formed, encouraged by the publisher-entrepreneurs.
"industrial landscapes" emerged: Here, regional concentration was only slightly inhibited by the decentralized nature of wood and water power.[9] The sore point of the decentralized mode of production was the impossibility of controlling the work process. This became fatal where the quality of the product could no longer be seen at first glance: this created a practical compulsion for centralized production.

The "wooden age" is a "social age", an epoch in the history of work, not least because the material wood required a technique in which craftsmanship and a feeling for the special features of the material meant almost everything. However, the contrast with the following period should not be overstated: Experience and manual dexterity were still very important in production afterwards. However, the transition from wood to iron opened up completely new perspectives for the organization of the production process, which devalued work experience in the minds of technicians. Steel mechanisms enabled higher pressure, stronger power transmission, accelerated speed and more meticulous precision in production operations. Steam power with increasing pressure, rotation and growth in size could now take full effect. The material became more homogeneous, friction could be reduced; the machine became calculable, or at least it was possible to imagine that in future it would be possible to calculate machines and design them for maximum efficiency. Wooden mechanisms quickly began to grind and squeak at higher speeds, under greater pressure and with more transmissions. For the engineer striving to make technology more scientific, the transition from wood to iron became a matter of principle, independent of economic calculation.[10]

Maximizing the use of renewable resources: this also meant developing creation of the power of humans and animals. As Michel Foucault notes:
"One of the great innovations in the power techniques of the 18th century was the emergence of the 'population' as an economic and political problem: the population as wealth, the population as labor or the ability to work, the population in the balance between its own growth and that of its resources." Presumably, this was one of the main driving forces behind the events. According to the prevailing view at the time, what mattered above all was tireless diligence and an improvement in work ethic.

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even more than the introduction of new machines. The ambition to get the best out of people led to a wide variety of con- sequences: academies and treadmills.

From a human point of view, this "wooden age" is highly ambivalent. Until the middle of the 19th century, the trend in German industry and - under the pressure of industrial competition - also in the skilled trades was towards longer working hours. The industrial exploitation of child labor reached its peak in Prussia in the 1940s. Even contemporaries linked both the spread and the subsequent decline of child labour in factories after 1850 to the state of mechanization.[11] However, child labour was not only a strong incentive for "unskilled" work on machines, but also where the pace of work and product quality could be increased if the activity became second nature to the worker from childhood. It was said that a miner could only develop a feel for the veins of ore if he had already picked ore as a child. Qualification through child labor: This was another way of maximizing the use of human resources!

The intensification of agriculture that began in the late 18th century, which kept the economic dynamics of the time going at least as much as the growth of trade, "consisted less in the introduction of new, labor-saving machines and techniques" than in the "compression of the peasant working year"; in particular, the workload of women and children was increased. The cultivation of the potato - the innovation that most changed the everyday lives of broad sections of the population - brought about a technical relapse into archaic hoe cultivation; it reactivated "working tools and methods that initially did not reach the technical standard of grain cultivation", and imposed arduous work on women and children in particular.[12] If the "agricultural revolution" was aimed at improving crop rotation and the balance between arable and livestock farming, this was more of a refinement of traditional agriculture than a new beginning. A deep break followed in the subsequent period, with the incipient chemization of agriculture; the contrast to the agricultural reform of the early 19th century was emphasized with cutting sharpness by Liebig in particular.[13]

The older agricultural reforms achieved the following with simple technical devices
major effects: The underpinning of stables alone, which enabled the collection of liquid manure, multiplied the nitrogen supply for agriculture. Significant progress was made in the improvement of the traditional plow - for example, with iron fittings on the plow sole - and in the use of scythes instead of the traditional sickles; mass steel production promoted the use of the plow.

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The general implementation of a technology that had been around for a long time. The most elaborate innovation on farms in the 19th century was often the horse or ox-drawn cart, a technology that was still being developed at the time; contemporaries placed it alongside the steam engine. Alongside humans, animals were still the universal source of power par excellence, and the technical use of this source of power was still on the increase at the time.[14]

Was the era based on regenerative resources blown up from within: by a systematic overexploitation of the natural basis on which it was based? Liebig branded pre-chemical agriculture as an overexploitation that was ruining the soil; today, this accusation would rather be directed at chemical agriculture.[15] In the case of forests, the thesis of pre-modern overexploitation and the resulting timber supply crisis dominated for the longest time; however, it too is empirically based on weak foundations.[16] The emphasis could rather be placed in the opposite direction: Today, interest in timber supply - globally speaking - generally no longer functions as an effective driver of forest conservation, as most timber consumers have moved far away from forests; two centuries ago, by contrast, this was the case to a high degree, as the flood of economically motivated warnings about "forest degradation" and "appalling wood shortages". The German reforestation movement is an achievement of that time, even if it later fell into the context of an industrialization phase that only needed the forests as timber producers and recreational areas. By the middle of the 19th century, when mass production and the general spread of coal began, the wood shortage alarm had long since died down. Coal became established not as a reaction to a shortage of wood, but as part of expansion strategies.

Was the implementation of steam power a reaction to the exhaustion of water power? Eversmann wrote in 1804 that in the Bergisch region "no unused gradient could be found for hours".[17] But as it turned out, even there, a further increase in the exploitation of hydropower was possible well into the 19th century if capital was invested; an absolute limit had by no means been reached. The rationality of dealing with limited regenerative resources also had a wide scope in the industrial age. Even a particularly dynamic branch of industry at the time, such as the wire drawing industry in the Bergisches Land, was still able to make do with water power throughout the 19th century, and sometimes even returned to it. The "wooden age" perished neither through ecological suicide nor through technical necessity.

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2. Innovation behavior in the "wooden age"

The old view that technology had essentially stagnated from the 16th century, the "agricultural age", until the Industrial Revolution, and that only steam and spinning machines had brought progress to an archaic industrial landscape, has been overtaken by more recent research.[18] It was based on a very specific image of progress: progress through construction innovations, by increasing the use of energy and by replacing human labor with machines. Contemporaries saw it differently. Poppe's *history of all inventions and discoveries,* first published in 1835, already describes a wealth of innovations that affect almost all areas of human life in some way. Most of these were product innovations. The mechanization of production processes was not yet the primary focus of attention. This reflects the innovation behavior of the time.

Even the early steel and engineering industries, recognized as leading sectors of industrialization, continued to use manual production methods in technical and organizational terms, not only in Remscheid and Solingen, but also in Sheffield. As industrial dynamics up to the 19th century, insofar as they were linked to regenerative resources, were subject to a compulsion towards decentralization - albeit not without counter-tendencies - all the technical progress that made production facilities more complex was slowed down. Even in England in the 18th century, innovation did not always mean mechanization, but very often a further development of manual techniques and an increased use of the division of labour. Some trades in pre-industrial Germany also went very far in this respect. The classic example is the production of sewing needles: According to one report from around 1800, this seemingly simple product passed successively through the hands of 80 workers, and according to another report, as many as 18.[19]

At that time, spokesmen for industrial progress were particularly skeptical of certain technical innovations based on experience and knowledge of the world, especially those that were costly and complicated, replaced human labour or did not correspond to the natural conditions and resources of German regions. Around 1770, Justus Möser, the admirer of English industry, nevertheless expressed skeptical irony towards the literary flood of innovations propagated for the agricultural economy:

"How would we poor people have fared if we had followed all the suggestions that have been made for ten years now to improve the land? If we had bought all the sowing machines and all the types of plows that have been praised and forgotten during this time? If we had sown all the fodder herbs and

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would have imitated all the tillage of which we have been painted such a glorious picture? "[20]

The agricultural historian Josef Mooser notes that the alleged rural
The "sloppiness" about which the reformers railed was often not based on inertia, but on experience, "since agronomic innovations up to 1850 without precise knowledge of the interactions of nature were fraught with high risk".

Especially the machines: When an article in the *Schlesische Zeitung in* 1844 praised them as a "means in the hands of God for the redemption of mankind" despite the weavers' misery and called it a humane principle to have everything that could be mechanized done by machine, this attitude was by no means common knowledge at the time. In 1845, Gülich declared in his Handels- und Ge- werbegeschichte that machines should only be used in Germany "if it is proven that their use is for the benefit of the country's population"; this public benefit had to be substantiated by facts and not deduced from mere theory.[21]

What was economically rational depended largely on the ideas people had about future economic growth. Based on the historical experience of the 18th and early 19th centuries, it was highly risky to rely on economic growth that would last for generations and progress rapidly, and to build factories that only promised to be profitable in a permanently expanding market. It was more sensible to regard strong growth as a temporary phenomenon. Gülich warned against the optimistic belief - which already existed in flourishing commercial regions at the time - "that consumption would not find its limits" and that growing production would create its own demand. If the national economic theorists - according to Gülich - had "consulted the eternally open book, history, more", they would have learned from the lesson
"Production generates consumption" is not a dogma, but rather the possibility "that a glut of the market could occur at almost all points on earth accessible to Europeans".[22]

From past experience, it was reasonable to assume that lasting good profits would not come from cheap mechanized mass production, but rather from the highly specialized production of luxury goods.[23] It is not even certain that this assumption has been completely disproved by history: If France still followed the path of luxury goods production in its industry in the 19th century and thereafter more than England, it was - according to one calculation - with the astonishing result that, despite the image of relative French backwardness, the productivity of industrial labor was higher there than in England, despite a lower use of mechanical technology.[24]

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At the time, it was doubtful whether it was in the interests of the common good for industrial growth in a region to far outstrip that of agriculture. Agrarian regions often enjoyed greater prosperity than distinctly commercial regions, and farmers typically made the best living in areas where they consumed their own produce rather than bringing the best to market: No less a personage than Max Weber noticed this. In typical cases, the "industrial boom" had a background of poverty and overpopulation, a lack of birth control and a labor force that could be exploited without limits. For large parts of Germany, supplying England with agricultural goods was more lucrative than industrial competition with England until well into the 19th century. There was good reason to believe that the ratio of input to output was more favorable for innovations in agriculture than for those in industry.[25]

Some of the German entrepreneurs of the time were obviously aware of all this - more so than later growth-oriented historians, who merely looked at things ex eventu. Johannes Schuchard, the Barmen factory owner and member of the state parliament, who knew the English spinning mills from his own experience and warned against English-style industrialization, considered the

The "enormous capital investment" required by a machine spinning mill was only bearable for a country whose inhabitants no longer knew how to invest their capital. In Germany, "English-style spinning mills" had not developed satisfactorily for 40 years, as capital could be better invested elsewhere. The Bielefeld textile merchant Gustav Delius expressed a similar view as late as 1842 in a *promemoria on the situation of the canvas trade and the spinning mill* in Ravensberg. One should not attribute the scepticism towards English industrialization merely to prejudice or even see it as a harbinger of the fatal turn of German nationalism, but also appreciate its sober economic and sometimes socio-political rationality. Schuchard, who advocated a "leisurely 'German' path of industrial development" (Rudolf Boch) and even had top Berlin officials behind him, saw the failure of the "Rhenish-West India Company", which went bankrupt in 1832, as confirmation that industrial mass production speculating on a global market without British naval power and without a British empire was doomed to fiasco[26] - the constant memento of German naval enthusiasts after 1900!

Even among Swiss cotton manufacturers, who can look back on an older tradition.

In the first half of the 19th century, after much toing and froing, "the consensus seems to have emerged that the competitiveness of Swiss spinning mills was based on low wages, not on the use of efficient but expensive modern technology". On the hesitant

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A wait-and-see approach to an industrialization strategy based on mechanical drive also led to dependence on water power - even if, on closer inspection, there were still unused reserves. In general, the "fully integrated factory", in which all production steps were mechanically driven, only became established in the German textile industry from the middle of the 19th century.[27] In 1854, the linen merchants in Bielefeld, who had previously feigned a shortage of capital, suddenly had enough money to found Germany's largest flax spinning mill: it was a leap from a cottage industry to a large-scale operation without any intermediate stages.

In the early days of industry, it was by and large not the technician-entrepreneur emerging from the skilled trades who set the tone and determined the industrial dynamic, but the type of entrepreneur coming from the commercial patriciate and publishing industry. This was true at least for the textile industry and for the larger companies that clearly exceeded the scope of the handicraft business. For this type of entrepreneur, technological innovations were generally not yet a central issue or an obvious method of increasing wealth. The same applied to the financiers of the time. Inventors were not yet generally regarded as respectable personalities; shady "project makers" had a bad reputation.[28]

Based on the experiences of the time, a private individual who did not have a sovereign behind him who was keen on prestigious projects was better suited to an economic system such as publishing, a combination of craftsmanship, homework and not very elaborate manufactories that kept investment capital to a minimum and minimized losses in the event of business stagnation. It was a type of rationality that still exists today, but was later eclipsed by the fascination with *economies of scale.* When people bought machines back then, they bought them as simply and cheaply as possible and not too many. Even Brügelmann initially set up no more than 16 waterframes and eight cards in Cromford near Ratingen, the oldest mechanical cotton spinning mill in Germany (founded in 1784): This was not an overly large investment in the overall business of this busy man and, moreover, a wise restraint; for Cromford, one of the alleged "birthplaces of the industrial revolution", was not a success in business terms, indeed it was a downright deterrent example for contemporaries. In addition to machine work, there was still a great deal of manual labor. Perhaps the most experimental Prussian entrepreneur of his time was Nathusius (1760 - 1835), who became famous as a tobacco and beet sugar manufacturer; however, he would have soon perished if he had specialized in certain technical innovations and not focused on a wide range of products, as the prudence of the wholesaler dictated.[29]

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When merchant capital finally did get around to making a major joint commitment to a technical innovation, it was not to increase production but to facilitate transportation: the railroad was the first large-scale technology to become respectable for continental European trading and finance capital. More than anything else, it marked the end of the "wooden age".

However, there were also types of innovation that were suited to the limits imposed by regenerative resources and whose rationality was based not least on this limitation. This applies in particular to the flood of recommendations for saving wood, which is one of the characteristic features of 18th century technological literature. Significantly, the parlor stove was at the center of these wood-saving efforts: It was not yet a technology for engineers and manufacturers, but a technology designed around the household - "oikonomia" in the old sense of "household economy" - whose wisdom Justus Möser proclaimed: "In war, some moments are great; in housekeeping, all, and none need be lost. "[30]

Nevertheless, some complicated mechanisms also corresponded to the conditions of the time. The most impressive example is the Jacquard loom, in which patterns could be programmed with punched cards, but which had to be operated by hand and at home and was still made of wood for a long time, as it did not have to withstand high speeds and loads. Mill technology was also on the move after 1700; "mills gained infinitely in the 18th century", Karl Marx noted in Poppe's History of Technology. Mill construction became a matter for specialists and an important client for the early machine industry.[31] An extremely important need of the "wooden age" was the improvement of fire extinguishers; a whole series of German inventors excelled here. Even in English fire engines, steam propulsion did not become established until the middle of the 19th century.[32]

Mercantilist politics agreed with old-style society in favoring innovations that saved resources, replaced foreign materials with domestic ones, helped overcome times of need and improved product quality. Even the guilds were not always as hostile to innovation as their opponents claimed. Journeyman migration favored the "transfer of technology" from region to region, at least to the extent that this consisted of an increase in the craftsmanship of the work. There were even tendencies within the guild system that promoted the division of labour and specialization.[33] In general, the guild offered the archetype of professionalization, and in this it was promising for the future. Although the idea that machines made workers' skills, knowledge and experience superfluous was sometimes associated with them, this was only temporary. The more expensive and complicated the machines became, the less

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In many cases, it was possible to afford unskilled workers who were unable to learn. From an international perspective, it is noticeable that successful industrialization was primarily achieved where there were guild-like traditions of professional work.

Until the second half of the 19th century, technical change, on the whole, still had little inner systematics and momentum of its own; as far as princely amusements and martial influences did not play a role, it was primarily oriented towards needs, and these were often modest.[34] The old philosophical ideal of needlessness and a simple life also existed among non-philosophers. Wasn't it nicer to walk in the fresh air than to rumble along bumpy roads crammed into a carriage? Poppe organized his history of all inventions and discoveries according to the various areas of human needs; in the end, of course, there remains a very extensive residual area, which is dubiously called "applied mathematics" and includes not only chemistry and electricity, but also mining. Occasionally, needs were invented for technical gadgets - "imagined needs" - such as for electricity, whose practical value was a long time coming, and in the 18th century its alleged medical benefits.[35] But the field of existing and imaginable needs was still broad and offered plenty of targets for innovators. Just think of the long unsatisfied longing for soft, light and airy fabrics on the skin! Or the adaptation of shoes to the right and left foot: until around 1800, the pairs of shoes were the same!

The material *wood* inspired the joy of experimentation, even the unprofessional ones.

sional, dilettantish: because it was available everywhere and in a wide variety of species, was extremely versatile and, on top of that, much easier to work than metals. Machines for working wood were much easier to build than those for working metal, and they could also run faster: an opportunity that the Americans of the 19th century in particular made extensive use of. In continental Europe, apart from sawmills, the mechanization of woodworking made only slow progress until the 19th century: After all, wood could be worked by hand, and manual labor was cheap. Even in the late 18th century, even the large manufactories that produced luxury furniture were keen to keep the cost of tools to a minimum. In many manufactories, only the tools already in use in the trade were available.

Wood favored manual work, but not necessarily the structures of the old craft; in fact, early forms of mass production were found precisely in wooden objects, not only in simple boards and spoons, but also in clocks from the 18th century onwards. While the famous artistic clockmaking of Nuremberg and Augsburg was losing its importance, around

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In 1720, the Black Forest saw the growth of village clockmaking, which was valued as an optimal use of wood; in the first half of the 19th century, more than 15 million Black Forest clocks were reportedly made by hand.[36]

Early textile machines were mainly made of wood: even in El- berfeld, in the midst of the iron industry, right up to the middle of the 19th century. They were therefore relatively easy to rebuild, and this happened surprisingly often: up to 20 to 30 times for one and the same machine. The entire innovation behavior was characterized by this: People didn't write off machines, they didn't replace them, they rebuilt them. Due to the high wear and tear of wooden mechanisms, individual parts had to be replaced on an ongoing basis anyway; this meant that there was a constant opportunity to make changes to details.[37] In this way, workers were able to adapt the machines to their body proportions and changing needs. The "fixed capital" was not yet as fixed as with ready-made steel machines.

In the "wooden age", industrialization was still an essentially regional process and was most strongly influenced by local traditions of manual dexterity, the agricultural conditions of an area and the regional forest and hydropower resources.[38] In the early 19th century, efforts to transfer technology between regions became routine, but the need to adapt an innovation adopted from abroad to regional conditions was still taken into account. Even then, some considered technological progress to be an irresistible natural process; others, however, believed that it was necessary to discuss whether a particular innovation should be adopted or not. In Bavaria, for example, there was a long public debate about whether railroads or canals should be preferred.

In the period that followed, it was the triumph of the railroad that suggested the irresistibility of technological progress more powerfully than any innovation before it.[39] While the debate on pauperism in the face of the famines of the early 19th century typically aimed to limit large-scale industry, its point was bent in the direction of industrial progress, especially by the railroad. In 1856, the "accelerated means of communication" - railroad, steamship, telegraph - strengthened Heinrich Bodemer's conviction that all regional and national differences in industrial development were obsolete. The forest and hydropower-oriented small and medium-sized industry, which still predominated in Saxony at the time, was treated with disdain by this calico manufacturer from Grossenhain.[40]

Even in pre-modern societies, however, there was generally *an* area in which the adoption of foreign innovations was considered necessary in principle.

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was held: the armaments of war. One of the origins of the engineering profession lies in military technology. The drilling of steam boilers was learned from the drilling of cannon tubes. And yet, on the whole, armaments production was not an overly important driving force of technical innovation until well into the 19th century.[41] However, the more trade took on the characteristics of war - a competition on which one's own existence depended - the stronger and more compulsive the drive for technology transfer caused by foreign trade became. The field of technology was lost as a social decision-making area: this was the most momentous change in the framework conditions of technological development.

3. Germany - an underdeveloped country? The technical profile of German regions in the 18th and early 19th century

In Greek mythology, Prometheus, defying Zeus' ban, brought fire to mankind and was then forged on the Caucasus at Zeus' command, where an eagle ate his liver, which was constantly growing back. In the course of antiquity - already a turn towards progress-optimism! - Prometheus was reinterpreted from a sacrilegious blasphemer to a benefactor of mankind; and the English Romantic Percy B. Shelley did the same in his verse drama *The Prometheus Unleashed* from 1820.

From then on, the "unleashed Prometheus" became a mythical icon of technological progress. However, Shelley himself was unsure whether the progress of mechanics would not make the hardships of human existence even harder. And as early as 1819, his wife, Mary Shelley, had already given the Prometheus myth a twist in the gothic romance: with her novel *Frankenstein or the New Prometheus*, which became even more famous than her husband's "Prometheus". Mary Shelley relocated Frankenstein, the inventor of the artificial human monster, to Ingolstadt: a sign that Germany, the land of Doctor Faustus, enjoyed a certain reputation during the Romantic period - and not without reason - as a land of maverick inventors and fantasists. But not as a country of successful engineers. Well into the 19th century, Germany was repeatedly and often harshly described as an industrially backward country, both by contemporaries and later generations. Even the tradition-conscious Justus Möser found the Germans hopelessly lagging behind the English in the skilled trades around 1770.[42] In stories of English skilled workers in Germany who, aware of their indispensability, showed off with arrogant behavior and excessive wage demands, Germany comes across as an underdeveloped colonial country. Joseph

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In 1798 in England, von Baader believed he had convinced himself of the "humiliating truth" that the Germans were "at least a century behind those islanders" in technology. However, he was one of those for whom steam power was the epitome of technical progress.[43]

Under the protection of the Continental Blockade, confidence spread for a time in the advanced industrial regions that they were already on the verge of catching up with English industry. This made the English superiority after 1815 all the more of a shock for many. Germany was known to be lagging behind not only England and the Netherlands, but also France, even Italy and Switzerland, when it came to adopting innovations, according to a judgment from 1821, which explained the backwardness from the longevity of the German national character, but also from deterrent experiences with innovations. Even if, on closer inspection, this inferiority existed primarily only in very specific textile and iron products, it was generalized in the collective memory. "Poor Germany, which was little more than a blank spot on the economic map in 1870" provided the contrast that made the subsequent rise all the more breathtaking.[44]

If we understand the "progress" of that time to mean above all steam and spinning machines, it goes without saying that England had a towering superiority over the vast majority of German regions until well into the 19th century. The picture changes as soon as the state of technology is measured against existing demand and regional resources. But even the foreign trade statistics do not match this impression of profound inferiority. Recent research has noted with astonishment that the export and import structure of German states in the first half of the 19th century by no means followed the typical pattern for underdeveloped nations - export of raw materials and import of finished goods; rather, the opposite was the case, with raw materials leading imports and finished goods - mostly from small-scale production - leading exports.[45] The small-scale production method at that time therefore not only met the needs of self-sufficiency, but also comparative cost advantages in foreign trade.

Until the age of the railroad, industrial development in Germany took place primarily on a regional, not a national, scale. Nevertheless, some general statements can be made about the industrial and technological profile of German regions at that time. There was a lively and growing exchange of innovation between German regions: not only in the mining and saltworks industries, where it is particularly well documented, but also in many other trades, such as glassmaking and measuring.

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ser and sewing needle production. Contemporary linguistic usage recognized "German" technology, albeit not always with full justification: in the Eastern Alps, a distinction was made between "Welsche" and "German" hammer mills; "German" furnaces were known in glass and brickworks; and the Bock windmill was considered a "German" mill.

The leading position of Central European regions in mining and metallurgy established in the 15th and 16th centuries continued to have an effect in the 18th and 19th centuries and was revived. Although the economic importance of the mining industry had declined considerably compared to other sectors of the economy, and in 1843 the *Kölner Zeitung* complained that "the ancient German mining and metallurgical industry was rapidly approaching its demise", declining yields often became a stimulus for innovation.[46] Growing mining difficulties encouraged geological studies and the improvement of prospecting methods. The mining academy founded in Freiberg, Saxony, in 1765 became the model for the *Ecole des Mines,* founded in 1783, and even the "teacher of mining to all parts of the world".[47] Advancement through science in an economically constrained situation: this began to become a typical German strategy at the time, which coincided with the educational pathos of the time.[48]

The *salt works were considered* part of the mining industry where they were subject to the sovereign mining regime. As a rule, they depended on the privileged supply of timber in a similar way to the mining and smelting works. Unlike large parts of Western and Southern Europe, which were able to obtain their supplies from sea salt mines, salt in Central Europe had to be pumped from brine springs and boiled at great technical expense. In this way, salt extraction gave impetus to technology. As with mining, the decisive factor from a technical point of view was the pumping equipment. At the Großensalza salt works near Schönebeck on the Elbe, which around 1770 had one of the longest graduation houses in Europe but had little water power, 350 people and 32 teams of horses worked in pedal mills that pumped the brine to the graduation plants. In many areas, the salt works were the largest consumers of wood; the more competition for wood grew, the more fuel became a decisive production factor.

"The secret of the salt works lies in the saving of wood", wrote Frederick II in his Political Testament of 1768. As early as the 16th century, the salt works became the preferred object of wood-saving artists. This innovative direction led to a large-scale technology of the early modern era: the construction of graduation plants, which were huge in comparison to the boiling houses and used solar energy to enrich the brine. They became the typical project of an entire generation in the 18th century

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Figure 5: The salt spring (the "Haalquell") in Schwäbisch Hall with its ten gallows, topped by huge, carefully stacked piles of wood: The timber supply was just as important to the salt works as the brine spring, and the warning of an impending timber shortage was used to make policy in the salt works town. Due to the risk of fire, it was forbidden to stack wood in the alleyways of Hall from 1682. The copperplate engraving from 1715 shows a rationally organized large-scale operation; however, the scoops with buckets hanging from them are still moved by human power.

of salt works reformers and already contained the typical pitfalls of large-scale technical projects: The cost-benefit ratio was almost impossible to assess, and the financial outlay forced and enabled intervention from above.

A significant conflict escalated in the 1730s over the project of a graduation works in Schwäbisch-Hall: the city council, which wanted to acquire a share in the salt works in this way, justified the project with the standard argument of "wood shortage"; the boilers sneered that the wood shortages were a "more than 200-year-old problem", although the wood had always been "available in abundance". An experienced saltworks man described the "woodcutters" as a "real plague" on the saltworks; they were usually just

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were "soldiers of fortune and bagmen". "Project maker" became synonymous with "swindler" - the first early modern technological euphoria under the impression of the triad of printing, compass and gunpowder was followed by an initial disillusionment. Especially when it came to saving wood, people were aware that there were cheaper alternatives to the large-scale projects. In fact, the graduation works soon became a technical dead end: the development of highly enriched brines through deep drilling made them superfluous and created the conditions for the transformation of many salt works into health resorts.[49]

German regions - especially the Aachen area and Silesia - became world leaders in zinc production during the first half of the 19th century.[50] *Zinc had* long been in practical use in the form of brass, as a component of which it had been identified by the chemist Stahl in 1718; however, its field of application was greatly expanded in the 19th century. Roofs made of sheet zinc, which began to be produced by rolling at the beginning of the 19th century, were slower to catch on in Germany than in England, France and Belgium; instead, zinc casting was developed in Prussia, which made the cheap mass production of building elements possible. Hard coal was introduced in Silesia around 1790 to extract the cheap zinc, which did not tolerate high firewood costs. Later, the abundance of zinc provided the impetus for the invention of zinc paints, which helped to establish the Rhenish paint industry and were used as a protective coating on the railroads. The fact that zinc, when dissolved in sulphuric acid, produced electricity, fueled speculation even after the middle of the century that Germany had a source of energy superior to English coal in the form of zinc.[51]

One of the most famous German innovations of the 18th century was the reinvention of Chinese *porcelain* by Johann Friedrich Böttger and his colleagues in Meissen (around 1710). This achievement was also part of the mining industry, as one of the main problems was the control of high temperatures through appropriate kiln constructions, and Böttger, a journeyman apothecary, benefited from the cooperation of Freiberg metallurgists. Porcelain production only reached technological maturity after a lengthy development process, which was also able to build on the saving kiln experiments that were carried out with enthusiasm in many places at the time. It was the prototype of a luxury trade operated on behalf of princes; the industrialization of ceramic production took a different path.[52]

In most areas of luxury goods production, Germany was in the lead.
18. and also lagged behind other countries in the 19th century. In old southern German trade and commercial centers such as Augsburg and Nuremberg, arts and crafts had maintained a high standard in technical terms; however, overall it was noticeable that in Germany a

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The impression of a metropolis like Paris or London was lacking and the upper classes, who sought to outdo each other in prestige consumption, were narrower than elsewhere until the late 19th century. Only Vienna developed a splendour and tasteful luxury consumption in the 19th century that could compete with that of Paris.[53] The impression of paucity that Germany gave was caused above all by this relative lack of splendour and elegance, and not so much by the material equipment of the life of the broad masses; this can still be seen in the comments on the world exhibitions in the second half of the 19th century. The observers sent by the French government to the Berlin Trade Exhibition of 1844 criticized the fact that German products, although inexpensive and technically praiseworthy, bore "the stamp of frosty and serious usefulness". German production retained this reputation for decades, even in the eyes of German experts.[54] It was a blemish in the eyes of all those who held the excellence of craftsmanship in the highest esteem, but at the same time it shows that the conditions for cheap mass production in Germany were favorable in some respects.

The wood-saving veneering techniques, which are based on paper-thin processing, are

The furniture styles developed in the 18th century using tropical precious woods reached their highest perfection under the spell of Paris, while the German capitals lagged behind. On the other hand, the German furniture industry established new eras of design in the 19th century with the Biedermeier style and the Thonet chairs made by hot bending. Both types of furniture made more use of the natural properties of wood than previous styles and were aimed at a broader, albeit still affluent, clientele. Thonet was already practising a kind of mass production.[55] While exotic mahogany had dominated furniture fashion until then under the influence of the colonial metropolises - to such an extent that the world's high-quality mahogany stocks were almost wiped out in the end - the Biedermeier period brought domestic woods to the fore, and the Thonet technique was developed on beech wood, which until then had been used almost exclusively as firewood.

If there was not a single large metropolis in Germany, but a multitude of smaller centers, this decentralized structure brought more advantages than disadvantages from the time when it was no longer associated with a plethora of trade barriers. It corresponded to the decentralization of natural resources; but the rise of chemistry was also promoted by the pluralism of the German university landscape. The advantages resulting from the lack of an all-dominating centralized structure continue to this day; they contributed to the fact that a divide between technically highly modern and archaic sectors did not develop in German industry with the same sharpness as in many other countries.

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Figure 6: Production of complicated bends using the Thonet bentwood process (1929): The previously steamed wooden element is clamped in a bending mold. The Thonet technique played a pioneering role in the development of modern wood bending and wood gluing processes. To this day, wood bending in the production of Thonet chairs is skilled manual work that requires a great deal of experience. As manual labor has become expensive, Thonet furniture - originally intended as cheap furniture for everyone - has become "exclusive furniture".

Until the late 19th century, German production had a significant cost advantage over English production when it came to the labor factor: wages were lower in Germany, while the level of education and work ethic were by no means below the English level in many cases. German emigrants in particular made the industrious German a well-known type from the 18th century onwards: sometimes more so abroad than at home. "Who are the industrious, the artists in/Britain and Russia, Denmark/ And Transylvania, Pensylvania/ And Peru and Granada? - Germans they are,/ Only not in Germany. They fled from hunger to Saratov, to Tartary," lamented Herder in his poem "German National Glory". But the more opportunities his own country offered, the more the energy of work came into play here too. In the spirit of Max Weber's "Protestant Ethic", it seems that it was the work ethic, not technical innovation, that came first. Where labor discipline and flexible adaptation to changing market conditions were more important than machines, German products were able to

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compete with English at the earliest: Some contemporaries recognized this competitive advantage. In the first half of the 19th century, there was a more permanent workforce in German factories than in English ones. The incentive to replace people with machines and, by means of technical innovations, skilled workers with unskilled workers, was less in Germany than in England.[56] An awareness of the crucial importance of human labor for production success was never completely lost, or at least never for very long.

In the 18th century, Germany had a cost advantage over most regions in western and southern Europe when it came to *timber*. The extent to which it was wise from an economic point of view to exploit this advantage was disputed; at the end of the century, complaints were heard everywhere in Germany about the "dreadful shortage of wood". This was partly a reflection of the increasing monetization of the timber supply. It was a deep cut when firewood, which had traditionally been obtained via rights, became a commodity with a market price: It happened that the price of wood jumped many times over within a short period of time. The more iron production lost its wood privileges, the more intensive the efforts to save wood became. In the early 19th century, German charcoal ironworks were ahead of English coke blast furnaces when it came to fuel-saving innovations such as blast heating.[57]

In the 1920s, the Feilner pottery factory's wood-burning stoves were exported from Berlin to England and Eastern Europe. German wood-saving publications criticized the English stoves as fuel wasters; Andrew Ure, on the other hand, railed in 1838 that the Saxon wood-saving stoves penetrating the English market caused "headaches, numbness and illness", and that the health of the English was largely due to the open stoves. But at the London World's Fair of 1851, German stoves and ovens were able to hold their own against the competition.[58] From around 1800, German regions led the way internationally with a forestry policy that systematically increased the timber yield of forests in the long term through professional forestry management. Here too, German decentralization was an advantage: better than in centralized France, which had dominated the forest economy until then, regionally adapted forestry doctrines were applied here, albeit often only over time.

Complaints about wood shortages declined after 1800. Instead, Germany's relatively good supply of forest and wood products compared to Western Europe was recognized as an advantage. Wooden toys were among the best-known German export products. Friedrich List even gave the Germans the dubious advice to follow the railroads of forest-poor England.

"an iron-clad wooden track on sturdy oak rails" opposite

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[59] In the Siegerland and Franconian regions, oak wood was the basis of a flourishing leather industry; there, the rearing of tanwood became the most profitable form of forestry.[60] Germany was also still well supplied with potash, a particularly extensive form of wood utilization, in the first half of the 19th century - partly thanks to Eastern European sources of supply; therefore, the transition from potash to soda ash took place more slowly here than in Western Europe. When the decline in sales of firewood and potash meant that inferior wood qualities lost their market, paper production from wood pulp (F. G. Keller, after 1840) and from cellulose (Alexander Mitscherlich, around 1870) was invented in Germany; Mitscherlich was a chemist who taught at the Hannoversch-Münden Forestry Academy. However, when he himself founded a pulp factory whose emissions caused damage to the forest, he became unpopular with his forestry colleagues and was eventually forced to resign from his teaching position.[61]

Here and there in the first half of the 19th century, scientific excellence was already being praised as a particular strength of German technology, although from a later perspective there was still little reason to do so. Ernst Alban pompously claimed that the "History of Inventions" was "telling proof that many inventions from abroad were only scientifically investigated and perfected when they found their way to Germany". Already in the
In the 18th century, electricity was more a matter for professors in Germany than in Western Europe - and not always to their advantage. The first Austrian "railroad" was built under the direction of the Imperial-Royal Professor of Mathematics Franz Anton Ritter von Gerstner, whose erudition avoided some of the shortcomings of the empiricist Stephenson, but in the end produced a railroad whose rails came loose during the very first test run (1854); it could only be operated as a horse-drawn railroad.[62]

Chemistry was established as a separate subject at German universities as early as the 17th century, earlier than elsewhere; Germany was then a
"Exporter of chemists". An English observer in the middle of the
In the 18th century, the Germans were "by far the best chemists in Europe". In 1811, the Göttingen philologist Heyne called chemistry the "queen of the sciences". But this was the chemistry that had fallen under the spell of romantic natural philosophy and became the object of real hatred for Liebig. With the rise of exact science, France initially became the land of chemistry. According to the controversial Liebig, chemistry led a Cinderella existence in Germany and German chemists were despised abroad.[63] Later depictions give the impression that the chemistry that made German science and technology famous had sprung from Liebig's head, as it were. But the rise of the chemical industry in the Rhineland had already begun

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in the early 19th century, but for a long time it was carried out in an unsightly manner and with modest technical equipment. When this industry was "science", it was still something other than science in the sense of Liebig. It took generations before the kind of science considered typically German, with its staying power, far-reaching methodology, penchant for large-scale systems and insistence on permanent research, became a key factor in industrial practice.[64]

In the second half of the 19th century, *paint production became* the focus of industrial chemistry: an area that had been rather marginal in early modern chemistry. Some colors (cobalt blue) were by-products of mining. A number of German industrial centers - Augsburg, Berlin, Saxony, Wuppertal and the Lower Rhine - had a leading position in paint production and even more so in fabric printing, even by European standards, in pre-industrial and early industrial times. This is all the more significant as color printing was one of the key areas of industrialization in the textile industry.[65] The Franconian journeyman dyer Christoph Oberkampf became the master of French color printing in Paris under Louis XVI and Napoleon. Advances in calico printing played a decisive role in the resurgence of the Augsburg textile industry in the It was here, not in the spinning mill, that the transition to large-scale production first took place in the 18th century. The calico printing works founded there in 1759 by the inventor-entrepreneur Johann Heinrich Schule rose to become the "most important in the world" (v. Kurrer 1844). Schule did not remain an isolated phenomenon in Augsburg; on the contrary, colour printing was given new impetus there after 1800 by Dingler, Forster and Kurrer, whereby it entered a first stage of scientificization. While the mechanization of the printing process up to rotation, the adoption of the English roller printing press, was slow, progress was made in chemistry. In 1798, the German cotton manufacturer Theophilus L. Rupp, who had emigrated to Manchester, had written that the art of dyeing had "reached a high degree of perfection without the participation of the chemist", triumphed Kurrer in 1844, for about 50 years "the shining torch of chemistry had penetrated into the technical workshops", and the art of dyeing had "assumed a scientific form".[66]

However, the ideas of science and scientific production changed in the course of the 19th century; according to the new standards, the companies of the first half of the century were primitive and pre-scientific and the inventions came about through theory-free trial and error. But organic chemistry, which became a German specialty, was at that time "like a jungle of tropical countries", like "an immense thicket" (F. Wöhler, 1835); those who strived too impatiently for theory did not get far.

"In the mineralogical world, the simplest is the most wonderful," said Goethe

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(as Eckermann noted on February 23, 1831), "and in the organic world it is the most complicated thing."

Shortly after 1700, the invention of Berlin blue, one of the first artificial dyes made from blood lye salt and iron vitriol, was achieved by chance. In the Berlin industrial landscape of the early 19th century, dyers and calico printers stood out; they produced export qualities that could hold their own on the English and French markets. The increase in value compared to the raw product costs was twice as high for calico printing, so it was tolerable that the cotton had to be imported. Advances in mechanization, but at least as much in work discipline, are cited as reasons for the success of the Berlin calico printing industry. When it is said in 1819 that the Berlin calico printing works was unshakeable because it stood "on the firm foundation of scientific knowledge", one can already recognize the propagandistic topos that became a core element of industrial self-portrayal in Germany. At least as important was the fact that textile printing "demanded a great deal of variety", i.e. that it corresponded to a production method whose strength lay more in the people than in the machines.[67]

Around 1800, *linen production* was "by far the largest German trade" and of paramount importance for both domestic and foreign trade. The steep rise of German linen as an export commodity was still a relatively new phenomenon in the 18th century. Even then, it was interrupted by stagnation; therefore, the crises in the linen business in the early 19th century were not immediately heralds of a similarly steep decline. The production of linen - from flax cultivation and flax processing to bleaching - was extremely labor-intensive and was considered by contemporaries to be the ideal method of feeding the growing small and peasant population in the countryside. The linen industry was therefore promoted by governments in the 18th century wherever flax cultivation was possible, including in England and Switzerland, where linen was overtaken by cotton at the earliest stage. In Germany, linen was a fabric that was more resistant to mechanization than cotton, wool and silk. Around 1840, flax spinning machines were five to six times more expensive than cotton spinning machines. Unlike almost any other major branch of production, the linen industry flourished almost exclusively in the countryside, and its concentration in cities and factories did not succeed until the middle of the 19th century.[68] But from the perspective of decentralized industrialization, which made the best possible use of regional labour and resources, this was not a disadvantage.

Due to natural conditions and export opportunities, Germany was around 1800, almost as much reference was made to *wool* as to linen, which until

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The sheep industry had been the basis for the rise of the British textile industry from the 17th century. In the early 19th century, sheep farming reached a peak in German regions and shaped the landscape. As late as 1860, when the decline of linen could no longer be ignored, the Prussian statistician Viebahn emphasized wool as the strongest German bastion in the textile sector compared to England and France. But sheep farming was the prototype of an extensive form of economy; in socio-political terms, it was the exact opposite of flax farming. In the late 19th century, it declined rapidly in Germany; at that time, deserted Australia became the stronghold of wool production.

Wool processing was relatively easy to mechanize: Arkwright's spinning and carding machines were adapted to wool within a few years. Fulling, which had been carried out in fulling mills since the Middle Ages, was the oldest mechanically driven process in the entire textile industry; even for Adam Smith, the fulling mill was the epitome of a "complicated machine". But in wool spinning, the advantage of the machine was not particularly great: according to Schmoller's calculations, the mechanization of cotton spinning saved 24 times as much work as wool spinning! On the other hand, there were no socio-political objections to mechanization. The Cockerill brothers' wool spinning mill, founded in Berlin after 1815, was the most important textile factory in the Prussian capital at the time.[69]

The most controversial of all technical innovations in Germany during the 17th and 18th centuries was the *ribbon loom*. It was also
"ribbon mill", although - as far as can be seen - it was generally driven by human power, not water power. Whether it was of German or Dutch origin is disputed. In 1685, an imperial edict was issued against the ribbon mill; it was renewed in 1719. The establishment of the ribbon loom, which was unstoppable in most German regions after the middle of the 18th century at the latest, is an indicator of how the practice of administratively preventing technical innovations was waning at the time. Initially, ribbons were made from linen and wool, then also from silk and cotton. The rise of the textile industry in the Wuppertal to worldwide fame was linked to the ribbon loom.[70]

Before the introduction of the ribbon loom, ribbon production was regarded as the
"the noblest of all weaving arts"; for anyone who understood it - according to Hörnigk (1684) - had to "possess, as it were, the basis of all other weaving arts". From a purely technical point of view, the ribbon mill was similar to the old loom, but a worker could weave 16 or more ribbons at once instead of just one and required less skill than before. On the other hand, the improvement in production depended on a "very precisely calculated interlocking

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The "work processes" in the workshops were also interlinked. However, there was no technical compulsion for large-scale operations; on the contrary, ribbon weaving continued to be an important part of the production process right up to the end.

In the 20th century, ribbon weaving was a prime example of an industry that, although it made use of complicated mechanics relatively early on, retained its decentralized and small-scale production methods. At the beginning of the 20th century, many of the ribbon looms were still made of wood and were produced by local carpenters.[71] The strength of the ribbon weaving industry was based on its flexible response to the diversity of demand and changing fashions. In this branch of industry, mass production and small series production could be combined at an early stage.

Here, as with other products, we see the economic and technological dynamics of small things, which were easy to transport even before the age of the railroad, so potentially had a wide market, and for which early mass production methods could be introduced relatively easily. It was a typical discovery of the late 18th century that a lot of money could be made from seemingly small items if they were produced and sold in bulk; some contemporaries saw this as a special opportunity for Germany in relation to Western Europe.[72]

In Poppe's eyes, the hosiery loom, which had already been invented in the 16th century, was also "one of the most artificial machines in the world". It met with much less resistance in Germany than the ribbon loom, as it was cheaper to procure and also benefited the small masters. Perhaps the most famous invention of the Bergisches Land in the late 18th century was the lacing machine. A French emigrant reported in 1793 that "some knowledgeable Englishmen" had assured him "that their fatherland had not yet come up with a similar machine that would equal this one in simplicity and art". It was also driven by human power.[73]

The production conditions in the Bergisch and Märkisch small iron industry are comparable to those of the ribbon weaving industry in that the small-scale character was also successfully maintained here to some extent and an early level of partial mechanization remained relatively stable for a long time. Solingen cutlery enjoyed a similar reputation as export products as the ribbons from neighboring Barmen. The cutlery industry, which dated back to the Middle Ages, was "the oldest and most specialized of all iron and steel industries". In Solingen, the grinders had been separate from the blacksmiths since the late Middle Ages and achieved an even higher reputation; in Sheffield, a corresponding division of labor only became established in the 18th century. Even in the 19th century, Solingen was never very far behind Sheffield in technical terms; if it was nevertheless at times far outstripped by its English competitors in terms of sales, this was due to the better quality of

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raw materials supply and infrastructure in the rising steel metropolis of Sheffield.[74]

In general, German *iron and steel processing* in the 19th century is characterized by the fact that forging processes retained a wider field of application for longer than casting, rolling and iron-cutting techniques. The famous Styrian scythes and, from 1770 onwards, the Remscheid scythes were made entirely by forging and hammering; this was no mere backwardness, but replaced the health-destroying grinding and made it possible to resharpen the scythe again and again by simply hammering it in the field. In the late 19th century, Solingen gained a lead over Sheffield in the partial mechanization of the forging process for cutlery by means of pre-stamped moulds on the forging hammer (drop forge), which enabled variable small series production. The steam hammer brought about an industrial revival of German forging traditions. The "Hammer Fritz" became the symbol of the Krupp company, which tried to conceal the replacement of forging by rolling processes from the public in the seventies of the 19th century. In the 1950s, Opel workers were still amazed when crankshafts were no longer produced using steam hammers, but with forging presses, following the American model.[75]

The spread of music and the woodworking trades in Germany led to to the early development of *piano making*. Nowhere was the relationship between new technology and culture more intimate than there. The 18th century saw the rise of the pianoforte, which was based on an improved hammer technique and was capable of expressing emotional waves. In the Romantic period, the piano had gone from being a luxury object to a standard fixture in middle-class homes; "the piano plays, beats, drums and drones alle", wrote Schubert. Zumpe, a native of Fürth, introduced the "forte- piano" to England in 1765; the Strasbourg cabinetmaker Erard moved to Paris in 1768 and founded the first French piano manufactory. The German piano maker Tobias Schmidt was commissioned to build the guillotine by the French National Assembly in 1792, as he only asked for a sixth of the price that his French competitor demanded.

One of the largest and most complicated pre-modern mechanisms was the *organ*; there was a technical connection to the smelting furnaces via the bellows. In the 15th and 16th centuries, Brabant, one of the earliest centers of the proto-industry, was the stronghold of organ building. In the 17th century, Hamburg organ builders became leaders in northern Germany, and in the 18th century the Saxon organ builder Gottfried Silbermann, a contemporary of Johann Sebastian Bach, took organ music to its historic peak. In the first great age of the fortepiano, the organ became old-fashioned; but in the course of the

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The Bach renaissance, which began with the Romantic period, saw an upswing on an industrial basis in Germany, more so than in contemporary France. After 1870, an "over-engineered factory organ" - in the view of later organ revisionists - conquered German churches. In the era of the steam engine and the Wagner orchestra, which was caricatured by mockers as a musical steam machine, the Hauptwerk, which produced the leading voices, was built "powerfully"; with the "Crescendo roll" it was possible to "swell the sound of the organ from the most delicate pianissimo to a roaring fortissimo". After 1900, on the other hand, the Bach Renaissance inspired by Albert Schweitzer called for a return to the Silbermann organ, to meditative inwardness: this too is one of the cycles of technical and cultural history!

Figure 7: The steam engine as a contemporary metaphor: "Die Bayreuther Ton- kunst-Dampfmaschine", from the Wiener *Humoristische Blätter* 1876, with Wagner's father-in-law Franz List at the piano, the piano manufacturer Bösen- dörfer as stoker at the furnace, and the smoke billowing from the trombone in the upper left corner forming the silhouette of Richard Wagner. To ears accustomed to Viennese classical music, Richard Wagner's music seemed booming, like an echo of the new age of steam power! The Philadelphia World's Fair opened with the pounding of a steam engine and a march by Richard Wagner.

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The most famous invention of pre-industrial Germany was the *printing press*. From a critical point of view, Gutenberg as a historical figure has remained quite obscure to this day; but since the 18th century he has become a venerable legend, and the printers with their German founding myth became one of the most self-confident German professions. The Pietists turned the Bible into a popular book around 1700; and the Bible Institute of the Pietist Baron von Canstein could for the first time afford to leave the phrase for future editions, so quickly did they follow one another. Victor Hugo celebrated the art of printing in 1831 in "Notre Dame de Paris" as "the mother of all upheavals"; but even before the revolutionaries, the pietists in Germany knew how to make use of it. The Bible remained the biggest bestseller for the longest time.

Lithography, a highly unconventional technique for printers at the time, was invented around 1800 by the Bavarian playwright Alois Senefelder and quickly spread across Europe. Germany was not lagging behind in paper production either: the "Dutchman", which replaced the previous stamper with a roller mechanism, was introduced here faster than in France. Friedrich Gottlob Koenig, a trained printer and typesetter who invented the cylindrical "high-speed press" and built the first rotary presses for the *Times* of London, was the best known of the German mechanical engineers abroad at the beginning of the 19th century, although he was initially rejected by German publishers. The pressure, strength, speed and precision of this machine required an iron construction method; Koenig was initially only able to do this in London, since in Germany, as he later recalled, "only heavy and clumsy machinery made of wood could be produced at that time". In 1818, however, he established the first German printing press factory in the former Oberzeil monastery, thereby founding a specialty of German mechanical engineering that still exists today.[76]

Koenig was a unique case at the time. As long as the factories manufactured their large, sometimes wooden machines themselves as far as possible, mechanical engineering could not become a leading industrial sector. And yet the German engineering industry did not start from scratch in the middle of the 19th century. However, to the extent that workshops at the time specialized in mechanical engineering, they generally worked for local needs, especially for mills and mining. Future pioneers of mechanical engineering had to deal with this older, by no means primitive tradition of German mechanical engineering, which originated from the blacksmith's shop and the carpenter's workshop and did not know specialization and cost calculation.[77]

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4. Technology transfer and adaptation of new technology

Part of the image of a once desolately underdeveloped Germany is the fixed idea that, until the late 19th century, technical progress in Germany was generally due to the import of technology from abroad. The myth that the new always comes from abroad reflects - as the ancient historian Moses I. Finley marvels - a general pattern of thought: "It is a strange habit to deny any originality to the people you are looking at: All innovations always come from outside."

The technological significance of foreign travel and industrial espionage abroad has been described time and again: The travel narrative is, after all, an archetype of history.[78] However, travel can only have an immediate impact in technology when some competence is already present and only certain gaps in knowledge remain to be filled. The technological literature often paid more attention to foreign technology than to domestic technology, as it saw its particular task as providing information about foreign innovations. There was also a tendency to exaggerate the foreign origin of innovations. "Very often it happens that things are announced to us from abroad as new, and only just discovered, which we have known and used for many years." (Heinrich Weber, 1819)[79] A remark that could also have been made a century later about the propagation of "Taylorism" in Germany.

Until the 19th century, "technology transfer" was always personal; this should not be forgotten in the growing technological literature of the 18th century. Mechanics were unaccustomed to the written form of knowledge transfer; machines were not built from textbooks and essays, but rarely from drawings. The "papyrophobia" of technicians, which still exists today, was justified at the time, as literary information about new techniques often conveyed a misleading picture. The import of foreign technology was always an impressive process surrounded by anecdotes, involving trips abroad by German entrepreneurs and government officials and the recruitment of foreigners. The resulting technical change was usually more conspicuous than the changes made by the locals themselves. The idea that new technologies came from abroad reflected the disconcerting nature of the new. The real processes were usually more complicated. Foreign influences were most effective where they met and adapted to indigenous aspirations.[80] This explains the specific innovative role of religious refugees in the early modern period, for whom their host country was the new Canaan. Emigrants in particular, if they are successful in a foreign country

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depend on clever adaptation to the host country: This is as true today as ever.

The early modern archetype of an innovation thrust coming from abroad was the long series of innovations attributed to the "French": the *Huguenots* and the emigrants from the Spanish Netherlands. They brought some of the arts of French luxury goods production and the famous Flemish textile industry to Germany. Particularly in Brandenburg-Prussia, which until then had been poorly endowed, the Huguenots were associated with a splendid abundance of "gallantries" and luxury products of all kinds, from hats made of rabbit hair to jams and pâtés, even artificial flowers made from the cocoons of silkworms. The French religious refugees were generally credited with the rise of the "factories" - the division of labor, market-oriented mode of production - in Germany. The origin of Wuppertal's industrial prosperity was sought in the immigration of French and Flemish religious refugees, which - as more recent research has shown - did not actually take place. Even in the Prussian silk industry, where Huguenot origins are relatively well documented, the importance of trade imports is not as decisive as was previously believed; however, the Huguenots were relatively often the type of entrepreneur who was skilled in craftsmanship and technology. The French immigrants demonstrably contributed to the spread of important technical innovations such as the hosiery knitting loom and the filature (silk twisting machine) in Prussia. Dutch Mennonites brought the art of trimming and braid making to Danzig.[81]

The epochs of German technological history are characterized by various The spurts of imported technology were a characteristic feature of this period, which is not to say that the impetus for these innovations only came from outside. Northern Italy and Flanders are the regions of origin of an oldest layer of innovations, especially in textiles, arts and crafts and forging technology. France and Holland became role models in the 17th and 18th centuries; Holland with its hydraulic engineering, its improved windmills, the more efficient gang saws, the rag shredding rollers known as "Dutchmen" in paper production and the large-scale mining methods for peat, which was also considered the fuel of the future for a time in German regions before the victory of coal. According to Hintze, the "secret of the rapid and brilliant development" of the Krefeld silk industry lay "in its relationship with Holland", including the technology and production methods adopted from there. The same applied to the Bielefeld bleaching plant in the 18th century.[82] In the mining and metallurgy industry, there were technical role models in Sweden and in Schemnitz in Slovakia. After 1800, the influence of Belgium, the Netherlands and the Czech Republic should not be overlooked alongside the all-important English model.

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The German industrialization was the earliest continental European industrial state based on the English model; it increased in the 19th century to the extent that the dynamics of German industrialization were determined by coal and steel.[83]

Since the 1920s, however, the "Yankees" of the *United States were* not only perceived as an extremely enterprising people, but also as a particularly technically inventive one, all the more so as America was one of the most important foreign buyers of German manufactured goods at the time and, as Martin Kutz demonstrated, American trade had already made a significant contribution to making German export industries less dependent on England and France in the early 19th century. The Prussian district secretary Ludwig Gall used the experience of a visit to the USA (1819/20) to familiarize the Germans with American "quick tanning"; at the same time, he warned that the European "factory states" in the USA, "with inexhaustible sources of spirit and material and with quite outstanding skill in mechanical work of all kinds", whose achievements even in the short period since independence "bordered on the unbelievable".[84]

The American steamships and mills were particularly impressive at the time. The "American mills" had been propagated in Germany since the 1920s. This was an improvement on the traditional watermill, which could also be implemented without American help. Ernst Alban praised Oliver Evans as the pioneer of the high-pressure steam engine; Borsig based his first locomotives on an American model. The most important model for the Ludwig Canal, which was built between 1836 and 1846 and connected the Main with the Danube, was the canal from New York to the Ohio; in the eyes of German canal supporters, the Americans surpassed all other nations in canal construction at the time. At that time, the USA was not so much the land of hectic speed and maximum mechanization, but rather the Eldorado of a material culture based on unlimited land, water, forest and animal resources.[85]

The polemic against blind imitation of foreign countries has been one of the basic motifs of German literature since the late 18th century and is also encountered in discussions on questions of technology. At a time when the veneration of French culture in Germany was increasingly turning into Francophobia, there was already Anglophobia here and there as a counter-reaction to Anglomania.[86] Around 1800, when some were proud of the fact that the Bergisches Land was regarded as "England in miniature", when factories there were given the names "Cromford", "Birmingham" and "Sheffield" and Wuppertal rose to become the "German Manchester", the doctor Andreas Röschlaub railed fiercely against the fixed idea that one had to follow the English in all things.

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Germany should emulate England, especially in the burning of coal, and mocked the superstition that an enlightened person should not consider coal smoke to be harmful. If England really was the model in everything, mocked Röschlaub, then Germany should imitate the negro slave trade, the miserable mass housing and the increase in suicides. In the early 19th century, in the time of the Luddites and Chartists, it was above all the social explosives created by English industrialization that worried German observers and - similar to France and Italy - gave rise to the idea that Germany had to follow its own path of industrialization, which differed from that of England.[87]

Around 1820, even a liberal British economist like Ricardo was converted to the realization "that the substitution of machines for human labour is often very prejudicial to the interests of the working class". In England, mechanization became the subject of decades of public debate. So even if one took England as an example, it was reasonable in the early 19th century to be cautious about a type of mechanization that replaced human labour and promoted large-scale concentration. A nationwide discourse developed about this. In response to the industrialization zeal of Friedrich List, Württemberg's finance minister Weckherlin stated that "the factory is the most serious danger, because it educates people to be either beggars or rebels". And in 1823 he praised the industrial path of the industrious Swabian state: "Würtemberg does not shine with individual large factory institutes, but the whole of Württemberg is a factory, a manufactory, where we look into the huts of the countryman or the crowded streets of the townspeople." Even Mevissen, one of the protagonists of the new industrial dynamic in the 1950s, saw Manchester as a cautionary example in 1845 and recommended decentralized manufacturing development in order to avoid the "harmful" consequences of the English type of industrialization.[88]

The rediscovery of history in the late 18th century is reflected in the
The look back at the great era of German technology and craftsmanship in the 15th and 16th centuries, the time of Gutenberg and Agricola, was also popular. This gave people the confidence that the Germans in particular possessed inventive genius, and they were encouraged by the reminder that the English lead was not very old and was based on new inventions rather than technical improvements.[89] The insight that this was what mattered most was forward-looking: the improvement and adaptation of foreign technology was successfully practised by the Germans in the 19th century.

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Until the middle of the 19th century, adapting Western European technology to German conditions meant building machines and factories more cheaply and with less fuel consumption and not replacing human, animal and water power with the steam engine without necessity, but allowing manual and mechanized production stages to coexist and combining older with new technology, wooden with iron machine elements. As late as 1850, the brickworks owner Miesbach, the largest Viennese industrialist at the time, rejected brick machines and told his workers: "I have become rich through the machine of your hands, and I want to stay with this machine."

The adaptation of technology to current conditions consisted not only in the modification of foreign innovations, but also in the further development of traditional technology, whose development potential was far from exhausted around 1800. There were also transfer problems in this sector, for example with the windmill: a technology known since the Middle Ages, but whose general spread, like that of many other mechanisms of the "wooden age", only took place in the course of the modern era, with a peak in the 19th century. Unlike the waterwheel, the windmill was not tied to land and water rights and was therefore - at least technically speaking - independent of feudal rule. However, it was more expensive and more susceptible to repair than the water drive.

The most important innovation of the early modern period was the "Dutch" windmill, which spread across the windy plains of Germany in the 18th and 19th centuries. Here, only the top part of the mill (the "cap") with the wings was movable; the remaining part could therefore be built solidly and equipped with more extensive technical facilities. In the middle of the 18th century, the Englishman Lee invented a self-steering wind rose for the easily movable cap. While Leupold described the Dutch windmill in detail in his Theatrum Maschinarum, his successor, Johann Matthias Beyern (1735), warned against adopting this innovation, which was costly by the standards of the time, too eagerly. In most parts of Germany, the wind did not blow as reliably as in Hol- land; therefore, no one was advised to "spend a lot of money on the windmills of this country [...]; but where there is a lack of water, to have them installed as easily as possible [...]". Although the Dutch could offer the Germans their mill books for sale, "they could not sell their constant sea air and Dutch wind". He himself therefore wanted to
"our so-called Teutsche Bock mills". Bock windmills were made entirely of wood, which is why they were still cheaper in Germany despite the increase in the price of the oak wood required for them; they could also be dismantled and moved.

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The tenacious resistance in Germany to the introduction of the Dutch sawmill is particularly revealing. In Holland, the
In the 18th century, the fret or full gang saw, which contained several saw blades and sawed the logs in one pass, became widespread. However, this innovation increased investment and reduced flexibility when sawing boards of varying widths. Furthermore, an increase in the number of saw blades slowed down the machine unless the drive power was multiplied at the same time. As late as 1847, the author of a
"practical mill engineering" against the view "that we have lagged behind in the construction of cutting mills in so far as such mills are almost always arranged with only one saw"; these "simple cutting mills" work more effectively "with one and the same power simply because of the rapid speed".[90]

The history of *bleaching* provides a productive example of the various phases and adaptation difficulties of technology transfer. In the course of the 18th and 19th centuries, innovations of Dutch, French, English and Irish origin overlapped here. They brought about the centralization of a process that was still often carried out by women in the countryside in the 19th century and the increasing chemization and acceleration of a process that had previously been lengthy and mainly caused by the sun. The introduction of Dutch bleaching with whey and woad ash was still within the framework of traditional natural substances. Even when treating the linen yarn with ash lye, however, care had to be taken to ensure that the desired quality was achieved and the fiber was not damaged, all the more so as "in the refinement of the bleaching manufactory" - according to the mayor of Bielefeld Consbruch in 1787 - "mainly the pile of the linen hand was founded". Things became more worrying when milk was subsequently replaced by sulphuric and hydrochloric acid to speed up the process. The Bielefeld bleachers experienced a fiasco around 1800 when they used new methods to speed up the bleaching process as much as possible and spoil the canvas in order to fulfill a major American order. They were now suspicious of the "new fast bleaching method with hydrochloric acid" and warned against rushing into it. The Augsburg bleachers were particularly resistant to innovations - perhaps because they still had enough room to expand the lawn bleaching process.[91]

A critical situation arose primarily due to the use of *chlorine*
The so-called "rapid bleach", which was invented by Berthollet at the end of the 18th century and marked a milestone in the industrialization of chemistry. At that time, a risk discourse was already developing that seems promising for the future today. The handling of gaseous chlorine cost several chemists their health and lives; it was only the production of chlorine in powder form that was

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form by combining it with lime made chlorine bleaching practicable. However, it was initially uncertain whether this could be used not only for cotton but also for the more sensitive linen fibers; even the information from England was divided. Around 1810, natural and Berthollet bleaching were combined in Wuppertal. The Bielefeld bleachers remained suspicious for decades; when rapid bleaching was hastily introduced in Silesia during the 1920s as a reaction to the linen crisis and without the necessary expertise, it spoiled the fabric. Antipathy towards chlorine persisted beyond the middle of the century, especially in small businesses; "its danger to the health of workers was proclaimed, and the owners of natural bleaching plants did everything possible to deny the viability of rapid bleaching". The Augsburg chemist Kurrer complained in 1822 that the

The "delusion that rapid bleaching is harmful to the canvas" had become "the swan song for our canvas factories"; and again he invoked the "shining torch of the new chemistry", which was to bring a "beneficent light" into the darkness of this delusion. But he also indicated that the Berthollet process needed to be further perfected and "adapted to the locality". Chlorine bleaching was used more carelessly in paper production, where everything depended on flawless whiteness, but even there it had unfortunate experiences. Current efforts to move away from chlorine bleaching in the name of ecology have to some extent proved the old concerns right. In general, there could only be solid progress in industrial chemistry with a cautious approach; as we know today, the past was far from cautious enough.[92]

Weaving is a conspicuous example of a much delayed mechanization compared to England. Even the high-speed shuttle invented by John Kay in 1738, which could also be used on the hand loom, only became widespread in Germany in the early 19th century. This contrasts with the rapid reception of the incomparably more complicated Jacquard loom: where increased flexibility was required, people were more docile than when it came to simply speeding up the production process.[93] The early looms lacked flexibility: unlike the hand looms, it was not possible to weave finer fabrics with machines that were only suitable for coarse fabrics. Machine spinning in particular gave hand weaving a temporary spread that it could never have achieved with hand-spun yarn; however, it was the weavers who suffered most from sales crises.

It was not until around 1850 that the mechanical drive began to establish itself in looms. It was associated with greater technical complications than the light spinning machines; above all, it required a transition to iron production, while the spinning machines were still made of wood for quite some time. The technical advantage of the mechanical drive in weaving was

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less than for spinning; the most important technical improvements to the weaving process in the 18th and 19th centuries could also be applied to the hand loom. The fact that the spinning machine "only" replaced a typical sideline activity for women, while the mechanical loom was a traditional male trade, was of social significance. Around 1840, the Saxon textile entrepreneur Wieck still believed that machine weaving would probably never spread in Germany. The passionate public reaction to the misery of Silesian weavers in the 1940s was possible because the plight of weavers was not yet fatalistically understood as an inevitable consequence of technological progress. Even in the late 19th century, there was still a great deal of weaver misery; however, this was perceived more as a historical phenomenon in the time of Gerhart Hauptmann's *weavers*.[94]

A common thread in the modification of technical innovations in the "fire trades" up to the middle of the 19th century was the fact that, on the one hand, it was only partially advantageous to replace wood with coal and, on the other hand, wood had to be used much more sparingly than coal in England. In old iron regions, there was a long period of
"profitable combination between pig iron production with charcoal" and puddling powered by hard coal, which replaced the fresh hammer. The path from charcoal to hard coal was not as straightforward as it appears from a time-lapse retrospective, and did not correspond to any technological constraints, even if a stronger integration of iron production and hard coal production was not possible.
-processing was one of the most important technical advances of the subsequent period. The first steam engines typically served as an auxiliary drive for the blast furnace blowers in times when water was scarce, while the water wheel was still the regular source of power.[95]

The reception of *gas lighting* in Germany, and in continental Europe in general, fits into the overall picture. In the early 19th century, "philosophical light", like electric light towards the end of the century, became a sign of a new era; the night was no longer ruled by the moon and stars, but by human lights. The Brunswick court councillor Win- zer was already promoting gas light in a similar way to Oskar von Miller's later promotion of electricity; however, he was only successful when he went to England and anglicized his name to "Winsor". Flammable, luminous gas could also be obtained from wood; this had already been discovered in 1682 by the chemist and cameralist Johann Joachim Becher, who was also one of the first to conduct scientific research into coal gas as a mine inspector in England. However, gaslight was initially only able to establish itself on a large scale in England, where the gas was available in abundance as a waste product of coking. The initial risk of gas production was considerable: the purification of the gas to achieve a pleasant and even flame was a major challenge.

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This required a lengthy technical development effort; moreover, gas supply was only worthwhile if there was a large customer base and a pipeline system.

The history of municipal technical networks begins with gas in particular. As gas can be stored, the technical need for even utilization was lower than with the later electricity grids. Gas was dangerous; there was regular resistance to the construction of gasworks in the neighborhood. In the continental economy of fuel scarcity, gas lighting was slow to catch on until the middle of the century; the last oil lamps disappeared in Berlin in 1850. Significantly, the first continental gas light, the thermal lamp designed for wood gas by the French engineer Philippe Lebon in the nineties of the 18th century, was also conceived as an "energy-saving stove" and was thus part of the long tradition of wood-saving efforts. Lebon ruined himself with his invention and took his own life. Nevertheless, the thermal lamp need not be regarded as a historical curiosity, as the long-term future of the gas economy lay not in lighting but in heat generation.[96]

The need to adapt a technology adopted from abroad to regional conditions was particularly compelling in two areas: in *agriculture,* including the processing of its products, and in transportation. As early as 1769, Krünitz criticized the unchanged imitation of the English agricultural economy in Germany as a harmful "Anglomania". From 1794, there was an ongoing discussion in German intelligentsia journals about the threshing machine, which had reached its first technical maturity in England shortly before. The proponents still argued remarkably little about saving wages; the opponents, however, pointed to the threat of rural unemployment: "Threshing machines make beggars and thieves. "[97] Generations passed before the threshing machine became established in German agriculture.

In the processing of agricultural products, the *distillation of spirits attracted* the particular attention of technologists around 1800, especially as its growing wood consumption became a nuisance in many places and it offered enormous technical possibilities for saving wood. Distillation was also a key chemical technology. The more some qualities of brandy became luxury goods, the more the drive for innovation focused not only on making the production process cheaper and faster, but also on improving the product; France was the great role model here.

However, a Munich professor warned against imitating the French distillation technique. This endeavor was not only doomed to failure because of the different nature of the Bavarian mash, but also because the distillation process would be too expensive.

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This was also because very few German coppersmiths - especially in the smaller country towns - had the necessary skills "to produce such composite apparatus as the French".[98]

Road construction was a sector where German travelers had been particularly sensitive to their own backwardness compared to France since the late 18th century. This was where the multistate system made itself felt, but also the widespread opinion "that bad roads were a blessing because it was harder for the enemy to enter the country and because they kept traffic in the country for a long time" (Schnabel). Based on the experiences of the Thirty Years' War and the situation of a transit country, this view was not unfounded. It was only towards the end of the 18th century that public opinion began to shift towards the fixed and still ineradicable idea that improving transport conditions was the economic panacea par excellence.

The Palatinate chief bailiff Lüder, who thought about a future German road system around 1780 and at the same time discussed the reasons for it,
"why there are still so many bad roads in Germany", saw one of the main obstacles to road building in the obsessiveness with which people in Germany stare at the French roads and always equate improved road construction with the construction of such magnificent roads, but are immediately concerned that the corresponding funds, labor and stones are not available in German regions. "The insatiable eagerness to drive on magnificent roads seen elsewhere has already tempted some people to give expensive orders and abandon exaggerated decorations"; and such examples then deter others from building roads. A road construction adapted to German conditions: this meant cheap construction, "completely without splendour and beauty" and only oriented towards need; it meant doing without compulsory labor, as forced labor "very rarely comes in handy", and the use of locally available stones, especially the overburden and slag from the many German mining and smelting works.[99]

Early pioneers of German railroad construction, such as Joseph von Baader and Friedrich List, propagated a cheaper construction method than the English one, as they believed that this was the most likely way to establish the railroad in Germany.[100] However, it is fortunate that the construction methods recommended by List were not implemented.
"wooden railroads" with iron-clad oak rails were not built and the cheap American construction methods he praised were not used in German railroad construction. It was often not possible to clearly determine what the technology adapted to German conditions should look like; railroad construction in particular was shaped to a large extent not only by natural but also by political circumstances.

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5. The state, technical innovation and ruling technology

It was above all the state that strongly counteracted the tendency of the late "wooden age" towards decentralization and the slowing down of energy-intensive industries; and it is also "indisputable" - according to Gustav Schmoller in 1870,
"that big industry in its entirety has long been the lap child of governments". But how should this state influence be assessed? The question of the historical role of the Prussian state and other German states in the beginnings of industrialization always easily becomes a fundamental question about the innovative role of the state and tends to be answered from a principled position, while the empirical findings are ambiguous. In retrospect, the centralized state enterprises often appear to be dead ends of development; it has rightly been emphasized that industrial dynamism emanated primarily from those regions - the Bergisch and Lower Rhine regions, the Kingdom of Saxony - where the economic intervention of the state was weakest. But if, from a purely economic and business-historical perspective, the role of the state ultimately appears less praiseworthy, a very different picture emerges with regard to famous technical innovations; for in the early days of the steam engine, the coke oven and cast iron, spinning machines and mechanical engineering, technical education and the transmission of information about the most advanced technology from abroad, state administrations make a visible and impressive appearance, at least on the European continent. In a history of technology that is concerned with people and events, the state is almost automatically assigned a key role. This can be theoretically substantiated if one considers Germany as an underdeveloped country at the time and assumes that the technical modernization of developing countries depended decisively on the state - especially on the militarily ambitious state.

In fact, significant influences of the state apparatus on the
technical development. Can we conclude from this that state intervention is necessary for technical progress? This in turn leads to the fundamental question of whether the progress of technology describes a large interconnected line in which no link may be left out and the market is not sufficient as a driving force. If we consider the early German steam engines and coke ovens to be pioneers and necessary precursors of later industrialization, then the Prussian state does indeed have a key role to play; for insofar as there was a Prussian technology policy, it had been strongly focused on such spectacular innovations since the late 18th century and pursued their introduction even without

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clearly recognizable economic need.[101] The situation is different if one assumes that technical development does not follow a guiding rope, but takes place on many levels, runs in different directions and is only given meaning by need. A broader investigation is then necessary to clarify the role of the state. The question is no longer to what extent the state has promoted technical progress, but which technical progress it has promoted at the expense of which other possibilities.

Silk production was the prototype of a new industry created by the state under Frederick II; two thirds of state subsidies for manufacturing went to it. Hintze describes the silk industry as a kind of key industry of the 18th century, around which "all the finer fabric industries" were grouped at the time and to which France owed much of its rise to become the "ruler of European fashion". But did the establishment of this industry in Berlin and the Kurmark really mark "the most decisive step" by which Prussia "entered the industrial competition of the European powers"? In the early 19th century, however, the silk industry was a prime example of how the businesses in the Prussian central provinces, which had been created with state support, quickly fell behind under the conditions of free competition, while the industry in the Krefeld region, which had emerged from private initiative, flourished and prospered thanks to its good trade relations. Brandenburg's silkworm breeding industry turned out to be a prime example of an artificially bred industrial culture that was not adapted to the geographical conditions.

While the silk twisting mills with their mechanically operated filatories in Italy, France and England were an origin of the factory system, this was hardly the case in Prussia. There were centralized manufactories, but the division of labour and specialization was less developed there than in the Lyon area. The commercially successful silk industry of the Krefeld region in particular worked in a decentralized manner, benefited from its flexibility and only introduced the mechanical loom late in the 19th century. The Berlin silk industry also returned to small-scale operations and publishing when it was exposed to free competition.[103]

Since, from the government's point of view, the lack of people, not the employment of an overly dense population, was Prussia's main problem, there was no fundamental objection to mechanization that saved people. Nevertheless, technical innovations as such were not a goal of Prussian economic policy until the late period of Frederick II; a notion of "technology" as a factor in its own right only emerged towards the end of the Prussian Empire.

18th century, when the "Techni-

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deputation" was established (1796). Until then, state-sponsored innovations had mostly remained within the framework of the innovation efforts characteristic of the "wooden age", whether it was about economy stoves or product improvements. The wool manufactory operated under the name "Königliches Lagerhaus" in Berlin did not provide any technical impetus either.[104] In contrast, the founding of a mechanical wool spinning mill and associated machine factory in Berlin by the Cockerill brothers in 1815 at the invitation of the Prussian state was a complete success, with state support limited to customs concessions and the provision of an old barracks. The indirect promotion of innovation, which largely left the course of events to itself, was far more effective than the mercantilist manufacturing policy and project-making, which fell into disrepute in the 19th century. The bustling Prussian Seehandlung continued the old policy of state-owned enterprises for the longest time; in doing so, it was partly dependent on the latest technology. but ended in economic fiasco.

From the late 18th century onwards, the leading figures in Prussian industrial policy - first Heynitz, then Stein, Reden and Eversmann, and in the early 19th century Beuth and Rother - can be seen to have a guiding vision of technical progress and a fundamental bias in favour of mechanization that was not based on current needs and was ahead of the mood in many lower authorities and private entrepreneurs.[105] In the 1920s, the Berlin trade authority went to "endless lengths" to introduce a bread dough kneading machine, but failed due to the "silent, tenacious resistance" of the bakers. Beuth tried in vain to implement machine spinning in Bielefeld and railed against the convenience of the "big capitalists" there, who idly waited "until Great Britain put the knife to their throats in fine goods too"; however, they saw how poorly the machine spinning factories founded with state subsidies in Silesia were profitable, and their wait-and-see attitude was nothing more than commercial prudence.[106]

The state's influence on technology was naturally strongest in the *mining, smelting and saltworks industries*: in the shelf companies, the traditional cornerstones of the sovereign's financial system. The steam engine was first used in mining. Around 1750, the Austrian government introduced the "raft furnace", the continuously operating blast furnace, at the Styrian Erzberg, while the Prussian government introduced coke smelting in Silesia at the end of the 18th century. When the economy was left to its own devices, industrial growth under the conditions of the "wooden age" led to a decline in the importance of this "wood-eating" basic industry in favor of the rise of less energy-intensive trades. But the in

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The interest in mining anchored in the sovereign administration ensured that the mining industry continued to be seen as the heart of the economy and was promoted accordingly.[107] The declining importance of mining was counteracted through scientification, thus contributing to the high social standing of this tradition-steeped economic sector: Men such as Alexander von Humboldt, Freiherr vom Stein and Goethe were associated with mining. The position of the mining industry in the state industrial hierarchy created a basis for heavy industry to become the leading industrial sector in the course of the 19th century - contrary to the basic trend of the "wooden age".

Wood-saving innovations in the salt works had always been promoted by the lords of the land since the 16th century, especially as the purely thermal boiling process was less dangerous to experiment with than the chemothermal smelting processes, which were shrouded in mystery. Large gra- ding plants were a typical innovation from above, sometimes oversized for the sake of the lord's interests, the expense of which exceeded the means of the old-established boilers. They soon lost their purpose in the early 19th century, when deep drilling led to the development of stronger brines.[108]

The entire field of *hydraulic engineering was* a particular target for state measures, as water management affected sovereign rights and it was easy to establish a state regulatory authority. Hydraulic engineering facilities were among the most complex installations in the mining and saltworks industry. An engineering expertise developed here that became a model for other sectors. Johann Gottfried Tulla, who was in charge of the regulation of the Upper Rhine from 1817 to 1828, the largest and most difficult hydraulic engineering project in German history to date, had not only studied at the Ecole Polytechnique in Paris, but also with a saltworks inspector and at the Freiberg Mining Academy. Many water wheels depended on mill canals, many timber consumers on drift systems; all in all, hydraulic engineering can be seen as a key technology of the "wooden age".

Can we conclude from this that the state plays a decisive role in technology? The famous French canal constructions, which were often regarded as a model in the 18th and 19th centuries, could give this impression. However, economic needs did not necessarily require such large prestige projects, but were often satisfied by narrower and shorter canals and by the development of natural watercourses; in Germany, such more modest undertakings were generally limited. Decentralized British canal construction by private consortia was economically more successful than state canal construction in France, despite the lack of overall planning. Timber transportation was particularly important; the construction of the drift systems

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was based entirely on the experience of the lumberjacks. The 450-metre-long Raxtunnel, which led through an Alpine ridge and served to supply Vienna with timber, was built between 1822 and 1827 under the direction of an illiterate lumberjack, the "Rax King" Georg Huebmer.[109]

When clarifying the technical merits of the state, the question of the value of *education* provided by state institutions is central. This applies to Germany even more than to many other countries, as education and science were seen as playing a key role in technological development here in particular. The Prussian State Councillor Kunth coined the maxim - also in defense against demands for protective tariffs: "In the face of the danger of being increasingly restricted by the efforts of the more advanced Western European factory countries, the help that can be provided by the state is contained in a single word: Education. "[110] The Berlin Industrial Institute established by Beuth after 1810 was not intended to train an engineering elite for the high civil service, but rather practitioners for the private sector; its workshop was the most useful. But here, as at other technical schools, the pursuit of elite education prevailed in the long run. The Gewerbe-Institut was not responding to a need that had arisen in the economy for highly trained technicians; rather, it often proved difficult for graduates of the institute to find employment commensurate with their training. Of all people, the later "star student of the Gewerbe-Institut", the
The "locomotive king" August Borsig, who exhibited his locomotive at the Berlin trade fair
The man who named the prize-winning locomotive of 1844 after Beuth was exmatriculated from the Industrial Institute at the time as "technically untalented", and even later his theoretical knowledge was admittedly "very weak". This discrepancy between his performance at the Industrial Institute and his practical experience was not an isolated case.[111] Mechanical engineering in particular, which was the key sector of industrialization more than any other industry, was still largely based on manual experience until the late 19th century.[112] The young Werner Siemens could not afford to study at the Berlin Construction Academy and therefore joined the artillery.

The engineer was a professional status originally created by the state; however, state institutions by no means had a monopoly on the technical knowledge used in practice. In 1837, an opponent of theoretical trade training posed the rhetorical question: "Is not all knowledge in trade life the result of experience, which, absorbed by the senses, transferred into life as an original, provides the most accurate picture of the material production of a country?" If literary sources often give the impression that priority in technical innovations is given to scholarship and state institutions, this may be an optical misconception.

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deception, since manufacturers already knew "from practice what Beuth's employees had read in magazines".[113]

In mining and metallurgy in particular, the high praise of science had been a German tradition since Agricola's time. "No profession in the world deserves more encouragement because of its general benefits than (that of) a skilled metallurgist," wrote Heynitz, "nor is the subject of invention more extensive in any of them, since the application of physics, chemistry and mathematics provides a wide field for it." In truth, the blast furnace processes were opaque to the scientists of the time; the emphasis on the scientific basis of a trade was primarily a matter of prestige. The practical value of the academic training of mining officials in the 18th century was by no means certain.[114] The same applied to the training of building officials, the technical elite of the late 18th and early 19th centuries; the prestigious academization of this career promoted historicism in official architecture in particular.

Precise measurement and technical drawing was a formal qualification of fundamental, epoch-making importance. Measuring instruments and exact drawings paved the way for the replacement of experience by analysis and the separation of planning and execution. The state-institutionalized training courses and the exact land surveys initiated by the state from the late 18th century onwards were certainly important in this respect. In the manufacture of measuring and observation instruments, there has been a close connection between science and technology since the time of Galileo, although for a long time science benefited more from technology than vice versa. James Watt began as an instrument maker; a "first technological phase" in Bavarian industrialization is represented by the
This was characterized by the "emergence of an efficient production of measuring instruments", which was given an important boost by government contracts.[115]

There were other ways in which the state contributed - sometimes indirectly and not always intentionally - to steering technological development in certain directions. In several ways, it worked to paralyze the self-control mechanisms of the old society, which stood in the way of economic growth: through his wars and reconstruction projects; through his peopling policy, which fought against the Malthusian rationality of broad sections of the population; through the growth of the residential cities, in which markets for new products and for early forms of mass production emerged; through the "economy" campaigns, which encouraged the more effective use of the all-round resource of wood; through the trade exhibitions, which staged a supra-regional competition of excellence. The importance of the authoritarian state for this technical progress, which led to an ever-increasing degree of mechanization, can also be seen in the unpo

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pularity of such machines that replaced human labor - a fact from which Franz Schnabel drew the conclusion: "If democracy had already existed at the beginning of the [19th] century, modern technology would have made it impossible. Craftsmen, workers and peasants would have voted together in parliament against the machine. "[116] Under the eyes of the continental European police and the standing armies, the machine storm could not become a mass phenomenon; in this respect, the German factory owners were even better off than their British competitors from the outset.

The "technical" approach in the figurative sense - as the "handling" of problems through certain fixed, routine and quasi-automatic procedures - was promoted by the state administration, especially since the reform period at the beginning of the 19th century, and became a general way of "regulating" social affairs that was seemingly neutral in terms of interests. While the machine had been a utopian model of the state ("state machine") in the 18th century, the reality of administration in the 19th century, when the mechanical was replaced by an organic state metaphor, came a little closer to this model.[117] Although liberalism rose to become the dominant doctrine, in the

In the 19th century, centralized rule was exercised more thoroughly than during the period of absolutism. The development of administrative techniques of rule made it possible to dispense with thickly applied ideologies of rule.

Technical networks that exceeded the capabilities of the private individual enabled a rational-functional justification of state authority. This already applied to some extent to the ever-expanding canal systems required by the Saxon mining industry in the 18th century, for example, but more impressively to the railroad and telegraph systems of the 19th century. A representative of the older historical school of German economics such as Karl Knies claimed in 1857 that there was an urgent human need for telegraphy and derived from this an economic and technical vocation of the state.[118] The state was not the origin of technical progress per se, but it did reinforce certain directions of technical development and profited from them. In the 19th century, however, it was at least as much the municipalities that benefited from the new technical networks; these required a growing apparatus of qualified civil servants. It was not until the 20th century that the extent to which modern technology perfected state power became apparent.

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6. The dynamics of thriftiness

Economic activity based on regenerative resources had its own rationality that lasted well into the 19th century. Within the
In the "wooden age", there were significant rationalization spurts and "economization" campaigns, for example in Prussia and Saxony after the Seven Years' War and then again in the nineties of the 18th century and the Napoleonic period; however, these economization processes were primarily aimed at making better use of the available resources and not towards the later industrial modernity. However, the question arises as to whether the pursuit of economical and optimal use of the available production factors, if pursued consistently, did not unleash a technological chain reaction that broke through the barriers of the "wooden age". One could imagine that the ever more perfect use of animal and water power by means of galleys, mills and finally turbines inevitably drove mechanization further and further forward, whereby certain mechanized work processes also exerted mechanization pressure on the other production steps, and that the ever more effective use of wood as a fuel logically led to larger furnaces, to thermal compound systems and to the acceleration of production processes.

In fact, there were wooden paths to *economies of scale*. One element of techno
The process of logical momentum, the generalization of certain technical principles, can already be observed to some extent in the industrial growth of the early 19th century. However, the preceding centuries show that a partial and limited use of technical principles can last for a very long time: The urge of principles to generalize is nowhere near as strong in reality as it is in textbooks.

If industrialization is to be traced back to the consistent application of a specific mechanical principle, it is obvious to think of the principle of *rotation.* From Reulaux to Sombart, the "application of the principle of rotation, the principle of turning around and around instead of back and forth" (Sombart), was understood as the basic law of machine development. Lynn White sees the "constant rotary motion" as a revolutionary principle that runs counter to the nature of living beings, i.e. - when applied consistently - leads to the mechanization of work; however, he assigns it to the technical change of the Middle Ages. In fact, the principle of rotation is more fully realized in the waterwheel than in the steam engine with its jerky back and forth of the piston. The waterwheel and the galley already offered a rotating drive source that could be best utilized if the production processes connected to it also rotated, such as the grinding mechanism of the grain mill. From a purely technical point of view, the waterwheel already contained the seeds of a kind of

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of mechanization, which also enabled the use of steam propulsion. It made mechanical interconnected systems possible; in the grain mill, the "vibrating shoe", which regulated the grain supply to the grinding gear, was also moved by the gearbox; hammer and grinding mills were "often connected to other branches of operation such as grinding and oil mills, hemp mills and sawmills" and allowed the operator to react flexibly to changing local demand.[119] Although the operation of waterwheel systems was often subject to seasonal fluctuations in the water supply, pond reservoirs ensured continuous operation for a certain period of time. However, the cost of wooden mechanisms was generally not so high that the amount of fixed capital would have put pressure on continuous operation.

As long as the cogwheels were made of wood, the energy supplied was used up by friction after just a few transmissions. Iron parts and drive belts expanded the mechanization potential. However, rolling mills with high energy requirements - an epoch-making innovation and particularly effective application of the principle of rotation in production - were only able to establish themselves to a limited extent on the basis of water power. Until the middle of the 19th century, the rolling of heated metal in Germany was usually only practiced to the extent that it saved charcoal.[120]

A decisive difference between water and steam propulsion was that the installation of a water wheel did not only make sense above a certain minimum size of operation, but was also possible for small operations - provided certain water conditions were met. With animal propulsion, there was a "downscaling" down to dog and even mouse treadwheels. Only steam power, which in Germany was usually only profitable at a certain plant size, brought a quantum leap in technology and an impetus for growth in size.[121]

The basic principle of mechanization and rationalization in general can also be seen in savings: namely when this does not mean a reduction in production, but an increase in the efficiency of certain production factors. At the beginning of the 18th century, Jacob Leupold already defined the machine as an "artificial work through which one can achieve an advantageous movement and move something that would otherwise not be possible, either by saving time or power".[122] In the way of savings strategies that increase productivity, a restrictive economy could turn into an expansive one - at least from a purely technical point of view. In general, however, in the reality of the 18th and early

In the 19th century, there was a clear difference between the frugality that comes from scarcity and the increase in efficiency that is a component of growth. The frugality born of necessity is rich.

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The focus was more on small, mostly inconspicuous solutions. A memorandum on the wood consumption of the Upper Palatinate iron industry (1802) notes that there was "a certain amount of wood conservation that only those who really feel the shortage understand, which can greatly reduce demand". There was a difference between ambitious wood-saving projects and practical thriftiness. In blacksmithing, charcoal burning and brick making, saving wood was a matter of skill and experience, not an incentive for technical innovation. In technological journalism, in regulations and competitions, however, saving wood increasingly took on an expansive, innovative character: it was a qualitative leap. The old, domestic way of saving was above all a virtue of women, while the new way of saving, aimed at increased efficiency, was an art of the inventive man, who achieved his goal not through self-restraint but through the use of technology.[123]

In heavy industry in particular, there is a direct physical correlation between growth in size and improved fuel economy. Was it already effective in the "wooden age"? After 1750, under pressure from the Viennese government, the "coal-robbing" lump furnaces were replaced by continuously operating blast furnaces ("raft furnaces") in the area around the Styrian ore mountain with the wood-saving argument. However, the indirect process now used required the additional process of friction, which was very fuel-intensive; if this was included, the indirect process consumed twice as much wood as the direct process. Only further technical improvements led to a clear fuel advantage for the blast furnace. At the same time, the size of the smelting works began to increase; in the charcoal age, however, it was slow and did not exceed a height of ten meters, as the charcoal collapsed at higher pressures. In 1793, a blast furnace in Vor- dernberg asserted that the charcoal "saving was an effect of its size"; but Eversmann was still not entirely sure of the advantages of the higher furnaces. Last but not least, the hardship of transporting wood helped to keep the growth in size within limits.[124]

Steel production in the crucible and puddling process, as well as in the forge, retained a manual character: The quantity to be produced in a production process was limited by the physical abilities of the individual worker. The production of the huge crucible steel ingots that made Krupp famous depended on perfect work organization, not on large machine units. If Engels is to be believed, the puddling process led to the blast furnaces in England being built "fifty times larger" than before; on the European continent, on the other hand, it was combined with charcoal blast furnaces.[125] The leap to *economies of scale* did not occur here until after the middle of the century with the Bessemer process. Pure

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From a technical point of view, this "refining without fire" was the ultimate in fuel savings, just as the direct processing of the liquid pig iron from the blast furnace in the Bessemer process made continuous high-speed operation perfect. However, this production system was a huge quantum leap away from the energy-saving techniques of the era of scarcity.

The maxim "the larger the company, the lower the production costs" dates back to the early days of the English textile industry. But the spinning machines did not yet exert any pressure to grow rapidly in terms of technology. Above the old textile mills that are still shown as sights today, with their rather monumental and castle-like exteriors, one must not forget that most early textile mills were small and unsightly in comparison. Even a poor devil like Robert Blincoe, who is still famous today for his account of the horrors of industrial child labor that he experienced first-hand, could, having escaped the worst misery, think of buying his own spinning machines with the money he had saved![126]

There was a trend towards increased size in timber transportation, partly due to technical reasons: the construction of wooden "giants" (chutes), making waterways driftable and the construction of raft canals were only worthwhile when transporting large masses. In rafting, highly paid helmsmen were saved by attaching several "Gestöre" (single rafts) together. The "Dutch" rafts on the Rhine were up to 400 meters long in the 18th century. But these were exceptions: The amount of wood available and the competition between the various waterway users generally placed strict limits on the growth of drifting and rafting. Efforts to save wood led to the replacement of the enormous wood-intensive giants with sledge paths.

In some cases, the reforms in agriculture actually worked against the growth of farm units. Since the 18th century, Austrian agricultural journalism has taken the opposite position to the thesis of *economies of scale*: "the theory of the lack of profitability of large-scale landed estates compared to small and medium-sized farms". This thesis can still be found in the agricultural journalism of the early 1950s: progress through intensification by the farmer who works on his own land and tackles everything himself. But even at the Ruhr collieries in the early 19th century, the focus was by no means on unlimited growth: "Throwing unusually large quantities of coal to the surface" - according to a memorandum by two Essen mine foremen in 1827 - "with disproportionately little benefit, cannot be compatible with the present and the future, as everything has its limits. "[127] At that time, the "limits of the coal industry" were not yet known.

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Figure 8: "Holzriese" in Lower Austria. Holzriesen were wooden slideways used to transport tree trunks in the mountains down to drifting rivers. They were moistened with water so that the logs slid better. When the giants were iced over in winter, the tree trunks shot downhill "as fast as an arrow"; the ice giant was therefore considered the "giant of giants" and the giant building the "point of honor" of the lumberjack in the high mountains. It consumed colossal quantities of wood and was only worthwhile when large areas were cleared. The giant was monitored at the bends so that jams could be cleared before large masses of wood were derailed: a very dangerous job!

Growth" is a triviality and not a bestseller topic! In pre-modern technology, there was an urge to achieve greatness, especially in construction: But this was an art of statics, not dynamics. The engineering culture trained in construction was in tension with the technical mentality of the mechanical engineers who emerged in the 19th century.

Acceleration is a particularly characteristic - technical and non-technical - basic principle of industrialization. It was already beginning to emerge in the early 19th century, and not only in the mechanized sectors of the textile industry. The series of "Schnell" (fast) compounds used to describe new production processes began: "Schnellbleiche" (fast bleaching), "Schnellgerberei" (fast tanning), "Schnellseifensiederei" (fast soap boiling), "Schnellessigfabrikation" (fast vinegar production). Already since the
In the 18th century, "saving wood and time" ("and wages" were sometimes

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mentioned in the same breath). In fact

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Saving wood and saving time were identical if breaks were eliminated from the work process during which the fire burned unused. Often, however, there was no identity, but on the contrary a discrepancy between the two goals. In salt boiling, the amount of wood required even increased when people "always hurried away with the vivid idea of finishing".[128] In "rapid bleaching", chemical bleaching, fuel took the place of solar energy. And it was not uncommon for the "time saving" to shorten the life of the workers under the conditions of the technology of the time.

A basic feature of the technical development of the industrial age is the replacement of conventional materials with new ones, which generally entail further innovations. This line of development also continued the savings strategies of the wooden age; *substitution* was already a way of saving in the 18th century. Today's readers may be surprised to hear Poppe state as early as 1812: "We are now living in the age of surrogates." He was certainly thinking of beet sugar, one of the most famous German inventions of the time, which was promoted in 1812 by the Napoleonic ban on the production of colonial cane sugar; he was probably also referring to chicory coffee, the "Prussian coffee", an invention that was by no means economically insignificant around 1800 and whose success was due to one of the first major advertising campaigns in German history. Sugar and coffee were among the main driving forces of the colonial trade, and the invention of substitutes was typical for a country without colonies, as was the imitation of exotic precious woods. The inventive Nathusius tirelessly sought to imitate coveted southern wines with local fruit extracts and sugar: Where traditional self-sufficiency and a love of experimentation met, inventing substitutes could become a passion. But such experiments straddled a slippery line between progress and counterfeiting. Surrogates only became an industrial driving force when they were no longer mere substitutes, but fully-fledged substances with possibilities of their own. This also applies to coal, which for centuries served merely as a local substitute for wood.[128]

Another fundamental process of modern industrial development is the *networking of* individual technologies to form a system. As we have seen, the ideal of the interlocking system was already present in the 18th century, but was based more on mechanistic models than on real technical possibilities. Even then, however, there were trends towards networking here and there. Network elements were particularly well developed in hydraulic engineering: whether in the Venetian and Dutch water protection and drainage systems, the canal systems of mining and other hydropower users, the brine pipelines of the salt works with their sometimes complicated pumping stations or the drift and raft systems of timber transport. In the wet element, the system had to be perfectly sealed; otherwise a lot of effort was wasted.

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However, these "networks" had to be carefully adapted to the natural conditions; a system autonomy decoupled from the environment and the self-dynamics of technology spreading to other regions did not get very far. In the textile and iron industries in the early 19th century, there were already some advantages to vertical integration and the coordinated mechanization of individual production processes; but there was no sign of a
There was still no talk of "system constraints" on a large scale in Germany.[130] Compared to water-powered plants, which needed water reservoirs and had to fight for water rights with every expansion, steam power even brought progress in terms of simplification - systemically speaking: not least this made it attractive.

Peter Weingart rightly remarks: "The fact that technology is perceived as something outside of society that eludes social reflection and political action is itself an astonishing phenomenon and would be a worthwhile subject of sociological and intellectual-historical analysis." In the beginning, it seems, there was more imaginary technology than real technology. Until the 19th century, the objectification of technology into an apparatus detached from the environment and the working person was more literary fantasy than reality; only in the copperplate engravings of technological literature were there already machines without people. While Agricola had not only written about the technology of mining, but also about the illnesses of miners, the cameralists of the 18th century described the mirror glass factories without mentioning the gruesome effects of the creeping mercury poisoning on the mirror glass workers.[131] It was not the systemic constraints of technology, but the obsessions inspired by technology that gave rise to the momentum of technical development, which is reflected in the nightmarish image of the "machine being" in Goethe's *Wilhelm Meister* (1829), slowly and irresistibly advancing like a thunderstorm.

The production process was still largely dependent on the
However, the fascination with objectified technology grew rapidly after 1800, and an interaction between technology and domination emerged at both state and industrial level. The pursuit of maximum use of human resources could lead to a progressive division of labour; however, this made people's work so "mechanical", so simple and repetitive, that it encouraged mechanization. When Gülich warned in 1845 that "industrial diligence" should be promoted in this way,
"that more consideration will be given to people than to capital and machines", he predicted: "we will perhaps build colossal technical facilities in individual places, but we will consign the most numerous and at the same time one of the best parts of the population to the greatest misery [...].

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see". At that time, the term "industry" was reified and lost its old meaning of "commercial diligence", just as the terms "factory", "manufactory" and "technology" were reified. Only now did Marx's idea of an anonymous momentum of capital, indifferent to human desires, become possible: it too was a reflection of an epochal technological-historical era.[132]

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III. The formative phase of the German production regime

1. From 1850 to the turn of the century: Unleashing and containing *economies of scale*

While no sharp break can be identified between pre-industrial and early industrial technology, the period around 1850 marked a significant caesura in the history of industry and technology. The kinetic energy of German industrialization increased in leaps and bounds. In the wake of railroad construction and joint-stock companies, the establishment of which was facilitated in Prussia after 1848, Germany experienced its first major industrial boom; industrialization took on the characteristics of a contagious fever. While early industrialization and its leading sector - the textile industry - was still dominated by a type of entrepreneur coming from trade and publishing, who tended to keep technical innovations within the realm of what was comprehensible to non-technicians, from the middle of the century onwards - especially in the newly emerging mechanical engineering, chemical and electrical engineering sectors - the technician-entrepreneur type was more common.[1] It can be found particularly among the industrial pioneers, from Borsig and Siemens to Duisberg and Robert Bosch. Entrepreneurs who came from a merchant background also distinguished themselves through their technical expertise and identified with complex technical processes, such as Krupp and other Ruhr magnates. Even Emil Rathenau, who was often contrasted with Werner von Siemens, the prototype of the inventor-entrepreneur, as the type of businessman and financial artist, was a trained mechanical engineer whose particular achievement was that, thanks to his technical expertise, he was able to correctly assess the advantages of large machines and carefully calculate the transition to the electrical central station.[2]

At Siemens, technicians were given priority over sales managers.
a tradition. Even when the company was converted into a stock corporation in 1897, the Siemens dynasty claimed to continue to "control the technical progress on which the future of the company and the value of our property is essentially based". But the banker Georg von Siemens complained about the

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company management in 1900, saying that these "gentlemen" could "not calculate".

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In the long run, technical interests could not take precedence over commercial interests - at least not in the civilian, market-dependent economy; only in the armaments sector did the hunt for cutting-edge technology in the 20th century find an area unaffected by economic considerations. Moreover, the rule applies that as the technical lead of the pioneers diminishes, market strategies determine success and the requirements of "marketing" have an impact on technical development. The market must first be created for new products; as soon as mechanization affects not only the production process but also the products, sales opportunities depend on a service network. Around 1900, it was no longer just the technical innovation as such that attracted all the attention; market observation, advertising, cheap mass production, advice and service were at least as decisive for success.[4]

With the growing dimensions of technical development, the *procurement of capital* became a factor in its own right. Most early machines did not yet require large-scale capital operations; railroad construction, on the other hand, changed the situation in leaps and bounds. Now, large-scale projects of this kind were still the exception; in general, even after 1850, capital was not very anonymous, raising capital through family and personal relationships remained commonplace, and industrial success improved the possibilities of self-financing. But certain directions of technical progress, which were associated with great expense and required staying power, were dependent on the financing conditions. The large banks preferred large industry as a business partner: the financing opportunities also resulted in a dynamic of growth in size. If German industry caught up with and overtook the far British lead in a spectacular way, particularly in areas of large-scale technology, this was not least due to the industrial commitment of the German banks, which differed markedly from the distanced attitude of the City of London. The relatively low level of interest rates in Germany made a capital-intensive production method worthwhile at a time when labour costs were not yet exerting a correspondingly strong pressure to mechanize.[5]

However, in order for technical progress to become creditworthy and
As the taste for airy-fairy project engineering was lost, he had to orientate himself towards certain standards that - at least apparently - made it possible to assess innovations; and the less the benefits of technical innovations were immediately evident to laypeople, the more so. This is one of the origins of the scientization of technology proclaimed at the time, particularly in Germany. Reuleaux, the most prominent mechanical engineering theorist of his time, served as an expert for the banks when assessing the Mannesmann tube rolling process, the technical and economic problems of which were not immediately obvious.

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Nevertheless, this proved to be unexpectedly tricky.[6] Emil Ra- thenau's skill lay not least in the art of inspiring confidence in his innovations among the financial world and also the state and municipal authorities.

The big coup at the Frankfurt Electrotechnical Exhibition of 1891, the 15,000-volt transmission over a distance of 175 kilometers, was a failure in terms of its immediate mathematical result, but it had the highly significant long-distance effect of increasing the creditworthiness of the "power current" in the eyes of the Swiss banking world.[7] From the middle of the century, the bank and the stock exchange became a determinant of technological development and helped to strengthen certain directions of technology. "Our banks are groaning under the weight of the money offered to them at 2 percent interest," noted the annual report of the Bielefeld Chamber of Commerce in 1851.[8] This was a new tone in Germany; the capital pressing for investment developed a thrust of its own. First it was the success of the railroads, and towards the end of the century that of electrification, which created archetypes of a creditworthy technical progress.

From around 1850, ore began to be converted into coal in Germany. In 1847/49 - after initial unsatisfactory attempts - the first functioning coke blast furnace in the Ruhr area was built, the Friedrich-Wilhelm-Hütte near Mühlheim. If the beginning of an era of coal and steel is dated to that time and set apart from a preceding age of regenerative resources, this is also justified in a deeper sense, even if an era can by no means be defined solely in terms of its strongest growth sectors. In Germany, the epochal turning point around 1850 was of greater significance than in other countries, as the majority of German regions were relatively rich in wood but poor in coal compared to Western Europe. After 1850, however, Prussia at least emerged almost abruptly as one of the most coal-rich countries in the world. From now on, it was clear that Prussia, not Austria, was the leading German power. Within Germany, new regional profiles and interregional divisions of labor emerged, with proximity and distance to coal becoming decisive. The success of organic chemistry gave rise to the idea that the Germans were predestined to produce pretty much anything from the metamorphoses of coal. Jacob Burckhardt, however, sighed in 1870: "Coal is modernity in its intrusiveness", "the true symbol of all disgustingly modern life".

While the main tendency in the early 19th century was to promote progress In the "wooden age", technical progress was now most impressive where the trump card of coal wealth was played. In the "wooden age", the focus was on the development

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The focus was on the particularly efficient use of wood, differentiated according to type and purpose; steel was now the material of the future wherever high demands were made. It was no coincidence that, unlike in other countries, the "railroad" in Germany was named after the new material; there had previously been "wooden railroad" projects.

Until then, coal had mainly been used as a local means of saving wood and had mostly only been mined close to the earth's surface in rural secondary industries, but now it gave rise to an explosive increase in industrial agglomerations and enabled ideas of limitless growth that had previously been utopian. From 1850 to 1855, German coal production jumped from around five to ten million tons; in 1817 it had been 1.3 million, in 1899 it exceeded the 100 million mark. Production in Great Britain was more than twice as high, but France had been permanently surpassed by Germany in coal production since 1848. The English observer Banfield wrote in 1846 that the Ruhr was home to factories based on the "principle of association on a large scale" that had "produced so much wealth in England".[9] The *economies of scale*, whose industrial effectiveness had been hampered by the advantages of decentralization in the wooden age, were unleashed in their dynamism. The increase in coal production in the Ruhr in the 1940s was associated with a huge technical and entrepreneurial quantum leap: the advance to deeper coal seams, which were covered by a previously impenetrable layer of marl. Deep mining on such a scale required high initial investments; large steam engines were needed for water extraction, which the Prussian mining officials were initially skeptical about; the winding towers became the landmark of the coal mines. The tunnels had to be planned as a large system from the outset and the shafts had to be lined with bricks instead of wood, as had been customary until then. In return, better quality coal was found in the depths, which dispelled the prejudice that the coke extracted from German coal was unsuitable for the production of high-quality iron.[10]

A huge, sensually impressive quantum leap was made at the same time. The Bessemer process, which was invented in England around 1855, was introduced in the Ruhr in 1861: a remarkably rapid transfer of technology when compared with the 40-year hesitation towards the puddling process and the excitement of this new technology: In the beginning, the workers fled when air was blown into the large "Bessemer bulb" and the jet flame hissed.[11] The blast furnaces, which until then had only slightly towered over the roofs of houses, grew to tower height, and steel production, which had previously been carried out in

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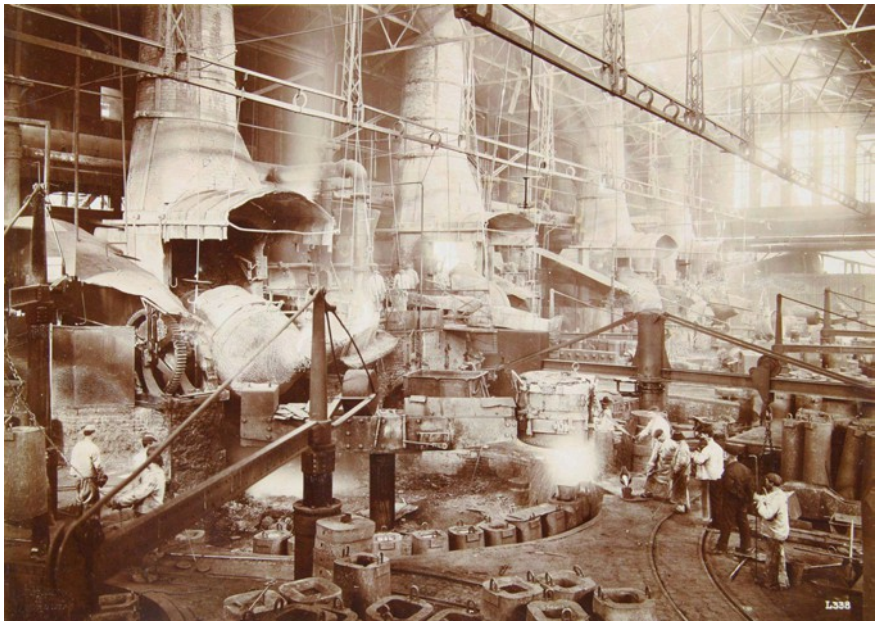

Figure 9: In the steelworks of the Krupp cast steel factory, before 1911. You can see the four "Bessemer pears": the pear-shaped converters into which liquid pig iron flows from the blast furnaces, which is converted into steel by the oxidizing effect of hot air blown in through nozzles in the bottom of the converters. On the right in the foreground, a worker makes a test casting. As the phosphorus content of the pig iron cannot be reduced with this process, the Bessemer process was not adapted to the German iron ore qualities; Krupp therefore acquired Spanish ore mines with phosphorus-free iron ore.

This large-scale network was the foundation of the Ruhr region, which from then on set completely new standards of industrialization in Germany and turned old-established industrial regions into backward areas.

The trend towards the spatial separation of pig iron production and further processing, which had developed on the basis of wood and water power and which stretched from the late Middle Ages to the early 19th century, now gave way to the pull towards centralization. The goal of vertical concentration from the coal mine to the steel end product, and even more: to the utilization of all coal derivatives and blast furnace and coke oven gases emerged. The ambition of the engineers was to network all these production processes beyond a spatial and entrepreneurial unification. The completion of an integrated economy of this kind became the signature of a new era after the turn of the century. Around 1890, the size of the da

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The complex plants required were a deterrent; it was also only gradually recognized that full-value products could be obtained from the coking plant residues.[12] In the era of mass steel, the scrap trade became a sector in its own right and scrap recycling provided technical impetus of its own: the Siemens-Martin process was based on scrap. This is why it lasted the longest after 1945 in the GDR, whose heavy industry was based on scrap for lack of its own ore deposits.

In retrospect, the second half of the 19th century is characterized not only by the transition to mass production of coal and steel and the combination of collieries, smelters and steelworks, but also by the limits of technical dynamics and the use of resources. In underground coal mining, manual labor and horsepower continued to be used for a long time; by the turn of the century, the number of pit horses was growing rapidly.[13] In steel production, the Bessemer process was not used more widely until the 1970s, when it was adapted to the ore qualities available in Germany. While the economic efforts of the charcoal blast furnaces had already led to the use of blast furnace gases in the early 19th century, the technology of gas utilization came to a standstill in the early days of cheap coal. Until the end of the 19th century, mechanical engineering was a separate technical sector from heavy industry with its own character. Even an integral coupling of the blast furnace and the Bessemer steelworks did not generally succeed, as the two plants had different production rhythms. In the ideal model, perfect production flow and optimal heat economy went together; in practice, conflicts arose between the two directions of rationalization.[14]

Heavy industry, mechanical engineering, later chemicals and the electrical industry: the

became - in the eyes of the Germans and the world - the four cornerstones of German industry and technology, all four connected by a network of endeavors and overarched by science. This industrial profile of Germany emerged in the second half of the 19th century; the full development of the cross-connections marks a new epoch after 1900. The influence of modern science - in the sense of a combination of theory and experimental research - also only reached many areas of industry in the 20th century.

The leading position of German heavy industry was based not least on the aura of power that surrounded it and on the gigantic impression of the plants. When Hoesch assured the Iron Enquiry Commission in 1878,

"our production" was "on a higher, more ideal footing than the English" may have seemed credible in Germany at the time; in reality, however, the German steel industry did not succeed in overtaking the English competition in the technical field until the early 20th century.

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overtake it. Rather, Germany held a leading position in the technology of non-ferrous metals, where early modern mining traditions continued to have an impact. England remained the leader in foreign trade in steam and textile machinery until the First World War. On the other hand, German industry achieved a leading position in machine tools, which it maintains to this day.[15]

Until around 1850, tar was an annoying waste product of coking plants; in the second half of the century, however, tar colors became the bright emblem of German chemistry. This required a lengthy technical development process and a change in perception. As late as the 1980s, synthetic aniline dyes were still reviled for their "inauthenticity" and their increasing use was branded a "dangerous evil"; it was not until 1894 that they were approved for uniforms by the Prussian military administration. At the end of the 19th century, however, organic chemistry seemed to have a special destiny in Germany: the predestination of a country rich in coal and lacking colonial raw materials, but leading in science. How German chemists conjured up bright colors from the black, greasy coal tar and, around the turn of the century, dealt a fatal blow to the famous indigo trade of the British Empire in just a few years: this miraculous process was one of the heroic stories of German technology and industrialized science that gave rise even abroad to the belief in the "German ability to turn dirt into money" and nurtured the hope that something similar would succeed with rubber, oil and even foodstuffs.[16] Chemistry turned coal from a mere fuel into a more valuable raw material. This gave rise to impetus for a more economical use of coal, which had initially been used wastefully, especially in the vicinity of mines. Later, the argument that coal was too good to burn, as it was used more efficiently by the chemical industry, served to legitimize the move into nuclear technology.

However, it was not until the end of the 19th century that chemistry found a basis in

of German coal, as the industrial intermediate link, the gas works and coking plants with their tar residues, had not yet been developed accordingly. German industrial chemistry had not sprung from coal and science from the outset, but originated from the "wooden age" and had its roots in the by-products of charcoal production. As late as 1891, Heinrich Caro, BASF's leading dye chemist, said of synthetic indigo production, the most ambitious goal of industrial chemists at the time: "No matter how this great technical problem finds its economically perfect solution one day, the sister industries of wood and coal distillation, a living and vanished flora, will always have to join hands".[17]

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Earlier than organic chemistry, which was based on carbon compounds, the potash industry, which is classified as inorganic chemistry, gained a raw material basis in the Staßfurt overburden salts, which quickly made it one of the world's leading producers. The Stassfurt "chlorine potassium fever" of the 1960s meant a radical upheaval for the traditional salt industry. The cheap potassium salts gave a strong boost to sugar beet cultivation as a fertilizer; the chemicalization of agriculture began with them. However, the extraction of chlorine potassium was based on a simple and conventional process.[18] In a history of technology whose main line leads to scientificization and complex processes, this economically important industry remains marginal.

The German electrical industry had its origins primarily in precision mechanics; only later did it enter into an alliance with coal and large-scale mechanical engineering. Initially, regions that were poor in coal but rich in hydropower seemed predestined for large-scale electrification. French engineers led the way in European turbine construction in the 19th century; after 1900, the Austrian Kaplan developed a turbine that could also be adapted to rivers with low gradients. The combination of steam power and turbines only made progress at the end of the 19th century.[19] A decisive advantage Germany had over England in terms of electrification was its less developed gas network. The German gas industry was slow to mobilize against the advancing electricity.

It is often the *crossing of boundaries*, the emerging cross-connections between different technological sectors, that establish a new style of technical development. This process of integration does not always take place continuously and from the logic of technical systems, but rather exhibits clear leaps. This can be seen, for example, in the electrical, chemical and mechanical engineering triangle: Towards the end of the
As the 19th century progressed, the task of linking each of these areas of technology with the other two became increasingly clear. In each case, there were characteristic barriers to overcome.

This might come as a surprise in the case of the electrical industry and chemistry, as there was an original connection between them: in the case of galvanic electricity, the generation of electricity was also a chemical process. The first dynamo machines, which used the dynamo-electric principle discovered by Werner Siemens in 1866, were used to split metal compounds. However, the enormous progress made in chemistry and electrical engineering in the following years gave both disciplines, whose boundaries had previously been unclear, a sharply defined profile of their own. This reveals a fundamental inner tension of modern scientific and technical development: the growing interconnectedness of all fields requires a boundary-crossing approach.

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However, this is becoming increasingly difficult due to the simultaneous increase in specialization.

Even Walther Rathenau, one of the founders of industrial electrochemistry - who, however, failed with electrolysis - wrote to his brother in 1892 at the age of 24: "Chemistry is not a science. You learn that stuff occasionally before you go to sleep or on the train. "[20] Mental barriers also hindered the creation of the link between chemistry and the coal and metallurgical industries, which laid the foundation for the cheap mass production of tar dyes based on domestic raw materials. The first tar dyes still had the "price of platinum", but in the 1980s the industry experienced a price collapse that made cheap mass production a question of survival. At that time, the coking plant, whose process still resembled the old coal mine in the forest, was regarded as primitive technology and a mere appendage of the colliery. In the 1980s, the report of a prominent metallurgist about his visit to a coking plant was met with "great amusement" among mining professors: "He had found the head chemist in wooden clogs in his laboratory there, the old-school man remarked caustically - a symbol, as it were, that the whole of coal chemistry was nothing more than a wooden science." It was not until the turn of the century that the scientifically trained chemist "replaced the all-powerful coke master" in the coking plants. From the 1980s onwards, the rise in the price of benzene led to coking being carried out in closed ovens as a by-product. The coking plant, until then a Belgian monopoly in its developed form, became a "German technology".[21]

The Siemens & Halske company, true to its tradition of precision engineering, pointed out

Until the advance of high-voltage technology in the 1980s, Siemens dismissed "every mechanical engineer as superfluous". The history of the Siemens dynasty is a good example of how the triumphant advance of "power current", including the combination of electricity and mechanical engineering, was accompanied by a generational break and demanded a new technical and entrepreneurial mentality. In the turbulent period of the electrical industry at the end of the 19th century, when high-voltage technology was expanding rapidly and the first "power stations" were being built, Siemens, the most famous pioneering company from the early days of the electrical industry, was paralyzed for a while; this opened up the space for the steep rise of AEG, which was headed by mechanical engineer Emil Rathenau.[22]

Looking back, it seems surprising how hesitantly the experience of mechanical engineering was adopted by the electrical industry and how "primitive" methods were used for a long time in the construction of electrical appliances. A particular technical challenge around 1890 was posed by the large power machines that were created when the new

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The central electrical stations were not designed as an addition to conventional drive machines, but as technical blocks. The strong initial resistance from experts clearly shows that such large machines represented a daring leap beyond previous engineering experience. The hope of significant cost degression was based more on economic than technical considerations. Oskar von Miller argued at the Frankfurt Electricity Exhibition in 1891: "If you now consider, for example, that a 400-horsepower machine requires no more operation and almost no more lubricant than a machine of 80 horsepower, you will be able to judge what progress the enlargement of the machine means for the cheap supply of electricity."

At the Paris Electricity Exhibition of 1881, an Edison machine of 80 hp was, as Miller remarked, "marveled at as a colossus"; in the 1990s, the 1,000 hp mark was quickly reached. But how clear was the rationality of such *economies of scale* back then? No less a figure than Edison explained that the work of several small machines could be better adapted to the fluctuations in electricity demand than that of one large machine.[23] Was the large-scale centralization of electricity supply - technically and economically speaking - rational at all, or did it first have to be made economical through territorial monopolies? The standing argument was the technical rationality of capacity utilization: the "valleys" created by fluctuating demand had to be filled; this was the argument used in propaganda for the power supply and the expansion of the supply areas. But these expansions created new "valleys" that could be used to justify new expansion spurts; they also increased line costs and reduced the possibilities of combined heat and power generation.

From a purely technical and economic point of view, a state of equilibrium could also have been achieved with small power plants. Compared to the first central power stations, the early block stations operated "relatively cheaply, as they only had a well-utilized network of lines with little expansion".[24] A considerable quantum leap on the basis of a regional monopoly was necessary for the central stations to be able to cope with this competition. At the end of the 19th century, this new ratio of growth in size was by no means generally understood. At the turn of the century, when German milling surpassed mining and the chemical industry in terms of production value, nine tenths of mills were still powered by wind and water; the 19th century was not only a century of the steam engine, but also a great time of mill construction. The basic idea behind the Kaplan turbine, invented in 1912 by the Austrian engineer Viktor Kaplan, who had close ties to his homeland, was to "reduce the size of a mill".

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The aim of the project was "to enable a better integration of the power plant buildings into their surroundings".[25]

Chemistry and mechanical engineering: this was also a field of tension of its own, which was more pronounced in Germany than elsewhere. On the one hand, the rise of large-scale chemistry placed increasing demands on technical equipment; on the other hand, the growing self-confidence of German chemistry hindered an integral alliance with mechanical engineering in training and professional practice. Heinrich Caro remarked in 1891 that the "art of engineering" had "taken possession of the chemist's apparatus and trained the often amateurish constructions of the chemical technician to the highest mechanical perfection". Unlike in the USA, there was no combination of chemistry and mechanical engineering in German university education at the time; the "chemical engineer" was fiercely resisted by Duisberg. The peculiarities and limitations of the "German way" in chemistry can also be seen in the fact that German chemistry at times left foreign competitors with a head start in plastics, even though plastics belonged to organic chemistry, the German specialty: resins were considered "indefinable" by the theory-conscious German chemists, and the "German way" in chemistry was considered to be "indefinable".

"were always thrown away, only crystallizable substances were regarded with pleasure", as they revealed the molecular structure. Emotional preferences of the laboratory initially kept German chemistry out of materials development.[26]

The second half of the 19th century as an epoch in the history of technology cannot only be defined by constant characteristics, but should also be understood as a *cycle* that results from the fact that certain trends, having reached their limits, also trigger counter-movements. In this way, a field of tension is created that continues to drive technological development to this day. The first great railroad boom was followed in the late 19th century by an unexpected upswing in inland shipping, "which no one would have had the courage to predict" (Werner Sombart). The rapid growth led to individual technological sectors taking on a life of their own, but also strengthened the networking of the various areas: a process that the technical sciences only ever followed with difficulty. Chemistry and technology gained in importance in the

At the same time, however, the weaknesses of a one-sided theoretical education became apparent and the necessity of experimental technical research was rediscovered. The resignation of Reu- leaux, the advocate of the new theory, from the academic teaching position (1896) and the rise of his opponent Riedler, the protagonist of experimental machine research, were a sign of this pendulum swing.

German engineers went from imitating foreign countries to becoming

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technologically independent, and even began to cultivate originality; now there was talk of "German thoroughness" and, according to the word

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Richard Wagner as "German", "to do a thing for its own sake", in the case of technology: to develop a machine to the highest technical perfection without regard to rapid profit. In the late 19th century, however, under the challenge of American mass production, criticism of the striving for originality and perfection and the call for standardization and market orientation also became a leitmotif of the discussion about German technology. One of Georg Schlesinger's commandments for the designer was: "You should not go about designing with a stick for invention." The same motif is still echoed today when it is mocked that German inventors "prefer to work for the German Museum and not for the market". The tension between mass and quality production, between flexible adaptation to buyers' wishes and standardization of products came to a head. However, these were not alternatives that were completely mutually exclusive. Around 1900, the mass production of machines also required precision work of a kind that had previously only been known in precision mechanics and custom-made products.[27]

Cyclical movements can also be seen in the assessment of workers' qualifications. While early industry mainly recruited its workforce from skilled craftsmen, the mass influx of unskilled workers, often from the rural proletariat, into the factories began in the middle of the century. While one of the management's main objectives was initially to break the factory workforce's stubbornness towards craftsmanship, a new industrial demand for craft-like skills subsequently developed. The value of an experienced skilled workforce was rediscovered, more so in Germany than in the USA.

Another cycle can be seen in the use of energy resources. While the "wooden age" was characterized by an increasing compulsion to be economical, the mass production of coal around the middle of the century initially led to a wasteful use of fuel - wasteful at least from the point of view of scientific technologists who were guided by the theoretical optimum of efficiency. Even in the seventies and eighties, the low coal prices provided little incentive for thermodynamic optimization of steam engines - to the chagrin of the scientifically ambitious engineers; because as long as efficiency was not important, mechanical engineering could be left to the craftsmen.[28] The founding of the Rhenish-Westphalian Coal Syndicate in 1893 marked a turning point: now coal prices went up by leaps and bounds. The gas and chemical plants also contributed to the increase in the value of coal. As in the "wooden age", the fuel economy became one of the main driving forces behind technical development. In the 20th century

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This trend intensified considerably during the war, interwar and post-war periods and only came to a standstill for two decades after 1955 due to the oil boom.

The fascination with large-scale technology began to radiate in Germany from the middle of the 19th century, but was soon met with counter-tendencies. At the beginning of this period was the railroad boom, at the end of the century bicycle fever broke out and the "power current" enabled mechanization on a small scale. As it turned out, there was not only a progress towards greatness, but also a progress towards miniaturization, privatization and the design of technology to fit the body. Even at the Vienna World Exhibition of 1873, the Krupp steel blocks, which grew larger from exhibition to exhibition, became boring even to Krupp admirers. Just as the general introduction of the Bessemer process was expanding the possibilities for steel production, the
"70 times higher than before", the "Great Depression" of the 1970s put a severe damper on these *economies of scale, the* effects of which lasted for decades. Egestorffsche Maschinenfabrik in Hanover-Linden, which had been bought by the "railroad king" Strousberg in 1868, began to outperform even Borsig from 1870 onwards through greater standardization in locomotive production, but was hit all the harder by the crisis shortly afterwards.[29] The construction boom in the metropolitan areas, which at times experienced explosive growth, led many brickworks to introduce the ring kiln, a German innovation of the 1850s: a prime example of *economies of scale*, it reduced the specific fuel costs to a fraction, but multiplied the investment costs and increased the vulnerability of the brickworks to the uncertainties of the construction industry. As long as manual labor dominated, the brickworks, like the itinerant brickmakers, could easily follow the building boom to other cities.

Last but not least, it is the ups and downs in the prospects of the *steam engine* that mark that era. The early German steam engines had started with an output of two horsepower. Ernst Alban had linked his high-pressure steam engine to the hope "that this machine could be brought into a duodecimal format and that its production could be transferred to smaller workshops, which is particularly important in Germany, where only very few places are equipped with all the tools for the production of larger machines". At the 1876 World's Fair in Philadelphia, German observers were delighted by the "cute" small steam engines that had "become a part of home furnishings in America". But this miniaturization was mostly uneconomical at German coal prices, especially as the trade inspectorate tended to take a more critical view of "dwarf boilers".

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The more the efficiency of the steam engine was optimized, the more "development was pushing towards the large steam engine". In this respect, there was an affinity between engineering science and the large engine; but for the same reason, the attitude of leading German engineers towards steam power was divided. The nothing-like-steam *mentality* of the English engineers did not characterize their German colleagues in the same way. "Dethroning the steam engine" was a tempting goal, if only because it meant overthrowing English supremacy in technology.[30] Redtenbacher was already dreaming of "putting an end to our present steam engines"; soon after the middle of the century, the gas and electric engines and also the compressed air drive began to occupy the engineers' visions of the future. Early hopes for the electric motor were disappointed until the 1970s; Reuleaux, on the other hand, praised small gas engines as "the true power engines of the people" in 1875. As late as the 1980s, "the professional world, led by Reuleaux, turned to compressed air" and thus temporarily put a damper on electric power; the Frankfurt Electrical Exhibition of 1890 was the scene of a duel between the electric and compressed air parties.

At the same time, the hot-air machine seemed to be the most popular choice for small drives with

However, it found little favor with engineers, while the advantages of the internal combustion engine were easy to see for the technical community trained in the steam engine. Compared to the steam engine, the direct transmission of power from the fuel to the piston without the detour via water heating and steam boilers made the explosion engine fascinating; however, it contradicted the technical ideal of smooth running. In this respect, the pressurized water drive received the highest praise. In 1884, however, a publicist working for the Centralverband Deutscher Indus- trieller (Central Association of German Industrialists) complained that the call for a small engine for the trades was a declaration repeated "thousands of times" without much happening in practice. In passing, he pointed out that new hand-operated machines had been introduced in America with "great success" since the 1950s. Innovations of this kind were more useful for small businesses in the 19th century than mechanical power sources. The pedal drive in particular still had considerable technical development potential; this was evident in both the bicycle and the sewing machine. The early highly specialized precision lathes at Bosch worked with foot operation. Not forgetting agriculture: around 1880, the engineer Lehfeldt invented the first usable milk centrifuge after a long period of development work. It was initially a steam-powered large-scale technology that forced the dairy industry to join together cooperatively. Subsequently, however, manual centrifuges were also developed. [31]

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Given the fame of Germany's cutting-edge technologies and the impression of growth rates, it is easy to forget that, measured by economic criteria, the ranking of importance is quite different in some cases. This applies not only to the internal market, but also to foreign trade. An official report by Joseph Chamberlain on German competition, which aroused public opinion in England at the time, stated in 1897 that German exporters were particularly successful in beer, hosiery, cutlery, musical instruments, pharmaceutical products, salt, sugar, toys and woollen goods. "There was hardly any talk of products from the most modern industries." (Pollard)[32] A cautious patchwork mechanization did not have to be a sign of small-mindedness, but could demonstrate economic rationality.

The era of high industrialization can also be characterized not only in terms of its - real or alleged - leading sectors and most sophisticated technologies, but also in terms of the boundaries between these areas of technology and the more traditional sectors. It is precisely the technological gap between the most modern and the more traditional sectors and the relationship between the different sectors that often becomes a social framework condition of its own. The partial mechanization of German agriculture helped to establish the position of power of the large agrarians even in the industrial age. An alliance between political conservatism and technical progress emerged, albeit only in its infancy; its full development took generations.

The course of major politics also left its mark on the history of technology. Werner Siemens, in his early days more oriented towards the British Empire and the Russian Empire with their earth-spanning cable projects, was, like so many German liberals, "firmly convinced" in 1866 that Bismarck
was "truly now gripped by the holy spirit of a great national mission". This turning point was not without consequences for the company's technological strategy. Although Siemens had started out as a Prussian officer and, according to his memoirs, had first discovered his technical talent during target practice, he initially viewed the war in 1870 "with horror from a business point of view". "But then the tide suddenly turned: military telegraphy came with extensive orders for existing equipment and urgent requests for new designs." In particular, new demands were placed on the photographic technology; "in short, the company found itself overnight in a situation that was completely different from what it had previously believed".[33] After 1871, Loewe introduced American-style mass production in the manufacture of weapons. The Zeiss company, which had previously sourced its lens glass from Paris, was subsequently able to build up a special glass production facility in the USA, not least with reference to the military value of optics.

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production in Jena the character of a national task and received the support of the Reichstag in 1884. After 1870, industrial circles that had previously been distant from armaments came to a positive reassessment of the military; engineers' interest in the war also increased.

However, the idea that armaments and war possessed a technological creative power and brought about technical excellence only became really popular with the maritime arms race around 1900. Riedler emphasizes that the war of 1870/71 was not followed by any significant technical progress, but "only a raw, unhealthy expansion of all kinds of enterprises"; it was the time of the founding years in which Reuleaux pronounced his famous verdict of "cheap and bad" on German production. Technical progress in the German steel industry has also often been overestimated under the suggestion of the Krupp myth. Despite the railroad, telegraph and needle gun, the Prussian military leadership was still far from seeing technical progress as the key to future victory. As late as the seventies, Roon wanted to replace the steel artillery with bronze guns. Crucible steel held its own in gun production until it was replaced by electric steel in the 20th century.[34]

While in the early 19th century it had often been thought that German industrialization was best complementary to that of Western Europe and that it made use of the gaps left by England and France, such ideas became old-fashioned, even contemptible, after 1871 at the latest. It now went without saying that Germany needed a broad industrial base and a corresponding sales market. Whereas the British fleet had previously been regarded as a guarantee for the worldwide sale of British mass production, the trend towards mass production in Germany now intensified the call for the fleet, especially as the "tempting chimera of the East Asian wholesale market" (Wehler) captured the imagination during the Depression.

The new German sense of power also radiated to the engineers and reinforced the basic feeling that it was no longer just a matter of imitating foreign countries or undercutting them with inferior goods, but of gaining its own profile and presenting top performance. Heinrich Caro, who moved from Manchester to Heidelberg in 1866, even said that "on the battlefields" German industry had found "what it still lacked: self-confidence, the awareness of its own strength". The battle over the Patent Act and the subsequent patent disputes, which became the most watched arena of struggle for technicians in the late 19th century, mark a time in which technical development was intertwined with large-scale industrial and state power politics. In a year like 1871, the cozy Heinrich Seidel himself described the engineers in his "Ingenieurlied" as

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In 1899, the student speaker at the centenary celebrations of the Berlin Technical University concluded his speech with the fanfare "that the technical universities may always remain the academies of war that supply us with officers in the peaceful struggle for world domination". In 1894, even Bismarck paid the chemist the compliment that he "decides on war and peace through his inventions".[35]

The Reich also sometimes took the initiative in the nationalization of technology. If Berlin quickly overtook Paris in the 1980s in setting up a telephone network, this was mainly thanks to Postmaster General Stephan. Siemens initially regarded the telephone as a gimmick, even as a "hoax". With this innovation, the Reichspost was not responding to an existing need - the ringing of the telephone was only very slowly penetrating German private life - but was pursuing the goal of taking an area that was sensitive in terms of power politics into state control and not allowing it to fall under the control of the American company Bell. However, neither the nationalization of the railroads nor that of the telephone system was conducive to the dynamic development of these technical networks. The Reichspost, which found "chatting traffic" annoying and unnecessary, saw the telephone primarily as a means of official business communication until well into the 20th century, and the Bundespost pursued a "rather restrictive" telephone policy until the 1970s. For the longest time, the telephone was not nearly as important for person-to-person communication in Germany as it was in the USA.[36]

With the rise of the technical universities, German engineering took on a more national character than before; stays abroad were no longer regarded as a high school for technicians to the same extent as before. When the technical universities of Prussia were granted the right to award doctorates in 1899 through the personal intervention of the Emperor against fierce resistance from the universities, the technical elite was at least outwardly placed on an equal footing with the traditional educated bourgeoisie. The desire to visibly present technology as a cultural achievement of the first rank, which arose from the social status mindset, was also one of the motives of the engineers of the time.

2. The railroad as a technology of national unification and the German slowness towards the car

From the very beginning, railroad construction was seen not only as a technical but also as a highly cultural and historical-political event, and rightly

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so. The eminent importance of the railroad in the 19th century - from economic, cultural and architectural to war and co

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lonial history - shows in an exemplary way that it would be too little to understand technology merely as an instrument and as an expression of other preceding forces, but that certain technological complexes become historical driving forces of their own kind. However, it would not be right to make the railroad the prototype of 19th century technology per se: This centralist technology, which relied on state backing and whose capital requirements were beyond the scope of credit systems based on personal relationships, stood in tension with the liberal, individualistic overall trend of the time, which resisted state intervention. Initially, some people could not see why the railways, like the roads, could not be used by a majority of transport users. The integration of rail networks into the economy and the state posed problems that were solved differently from country to country. The railroad systems and everything that went with them - line routing and substructure, locomotive and wagon design, bridge and station architecture, speed and bureaucratic organization - exhibited characteristic differences from state to state, which became apparent early on.

> "(I)n no country, with the exception of England, have greater expectations been raised.

"In no other country on the European continent has such a large number of railroads been built in such a short time. "[37] Railway construction in Germany took place simultaneously and in close connection with the rapid start of high industrialization. It was not preceded by a canal boom as in England or a great period of road building as in France; for the Germans, the railroad was synonymous with the leap from the Middle Ages to modernity in the transport sector, even if this transition was not quite so abrupt when viewed in detail. In the fact that the railroad gained a ground-breaking function and gave industry and technology new impulses, German conditions are more comparable to those in America than to those in other European countries. In his railroad propaganda, List held up the USA as a model for the Germans, even more so than England.

The conditions for railroad construction in Germany initially appeared to be "more difficult and more complicated" than in England and France. The railroad engineer Max Maria von Weber, one of the leaders of the rising engineering profession, recalled this in 1877:

"German technology was, so to speak, ambushed by the appearance of the railroad system in its infancy. It had not, as in France and England, been able to grow to manhood on mighty road and water constructions for ages, to develop admired masters and well-organized bodies and high schools, when the railroads demanded countless professional forces from it almost at a stroke. [...] Individuals, barely able to measure a parcel of land, became

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entrusted with the trac- tion of railroad lines, bricklayers' foremen, unskilled construction foremen, fitters and small foremen from mediocre machine factories suddenly developed into engineers, machine foremen, etc. of important railways. "[38]

Even if the German railroads did not emerge out of nothing to the extent that Weber dramatizes, German engineering, more than English and French engineering, was given a lasting and far-reaching initial impact by railroad construction, the traces of which extend through modern German engineering history to recent times. Whereas until then there had been a basic feeling that Germany's special opportunity lay in the small things that had been neglected by the rich nations, from then on large-scale mechanical engineering was regarded as the crowning achievement of German technology. For public opinion and general sentiment, the railroad became the symbol of modern technology par excellence; for here, for the first time, everyone - even those who had never seen the inside of a factory - was confronted with a large machine, and one that stimulated new perceptions, feelings and nerve impulses.

In addition to the lack of suitably qualified technicians, the second major obstacle to railroad construction initially appeared to be the political fragmentation of Germany. But for this very reason, even before the first railroads were built, the railroad prospects were immediately linked to the hope that this transport revolution would overrun Germany's internal borders. For the first time, the idea emerged in a suggestive form that a key national problem, which seemed hopelessly complicated politically, would find a technical solution. The hitherto omnipresent threat of famine, a constant stimulus to social revolution, also appeared to be technically solvable if the railroads could transport food from surplus to emergency areas at lightning speed and transport foodless proletariat to places where workers were needed. The German multistate system, initially a barrier, became a driving force behind railroad construction after the middle of the century, as a formal race developed between the German states.[39]

Initial reservations and resistance to the construction of the railroad were later greatly exaggerated: The aim was obviously to set an example of the absurdity of all attempts to slow down technological progress. Many books with mass appeal, from Treitschke's *German History* and Matschoß' *History of the Steam Engine* to Hitler's *Mein Kampf*, contain the alleged warning of a Royal Bavarian Medical Council that the mere sight of a train at full speed could make you mentally ill. However, this expert opinion, which has never been found despite all the searching, is all about

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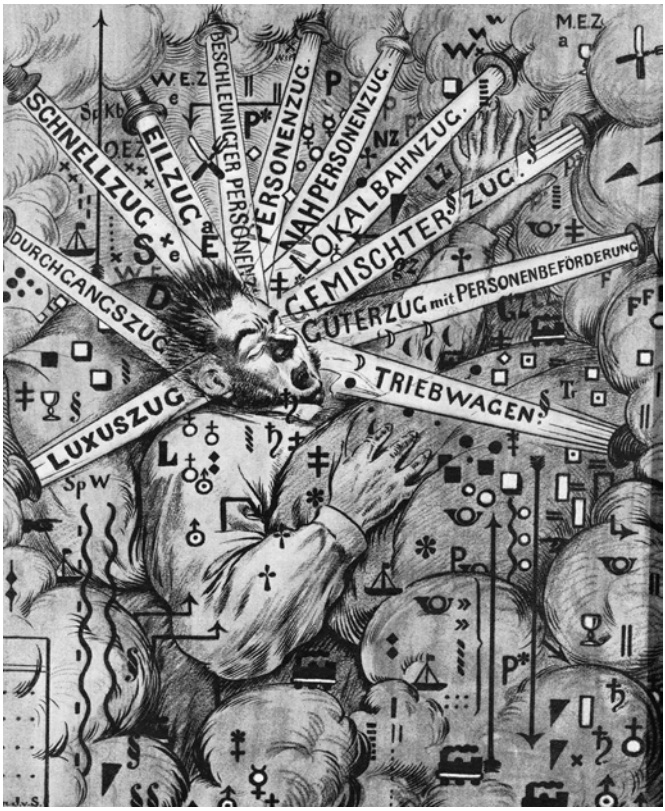

Figure 10: "Mr. Pimpelhuber's dream after studying the latest railroad course book": Caricature from 1904 - at a time when the idea that the modern pace was making people nervous had become commonplace and also already a target of ridicule. The increased pace forced people to communicate not with words but with symbols. The caricature basically betrays respect for the wide range of services offered by the railroads at the time and makes fun of the imaginary philistine, who only perceives this wide range of services as a confusing overload. Whether this type of philistine was still very common at the time is questionable.

It appeared to be a legend intended to denounce the supposed stupidity of technology critics. The skepticism towards the railroad that actually existed was generally rational and related to the considerable financial risk and the change in economic conditions that the railroad brought about. The Barmen factory owner Schuchard - not a fundamental opponent of the railroad - "shuddered at the terrible upheaval",
"if all main traffic is centralized and concentrated at one point":
"Whole areas can become isolated and sink into desert." Some of the controversies were simply about the speed of railroad construction. At the same time

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a cautious approach that waited for experience was sensible, especially from a technical point of view.

If one considers the far-reaching consequences of railroad construction, which were visible from an early stage, it is not the reservations against it that are surprising, but rather how little criticism in principle was voiced in Germany - even in comparison to France.[40] One reason for this may have been the con- servative aspect of the changes in location: The economic dynamism that had been striving out of the cities in the early modern period was brought back to the cities by the railroads; old inland trade routes, which had been reduced in importance by the rise of maritime world traffic, could be revived. The growth of the metropolitan areas, which had been at odds with natural conditions and had led to frequent supply problems as long as the economy was based predominantly on renewable resources, was given its technical basis by the railroads. But the proto-industrial decentralization of economic life, which had been hampered by poor transport routes, was also given a new chance in some regions thanks to the railroads.

In and of itself, however, there was no urgent economic need for railroads in large parts of Germany that could not have been satisfied by alternatives. Particularly in northern Germany - especially around Berlin - and in Bavaria, there were still many untapped opportunities for canal connections in terms of geography. Even if people were guided by England, France or the USA - and not only by the realities, but also by the projects - the canals were still considered to be the arteries of the future around the middle of the 19th century. Goethe, as he confessed to Eckermann on February 21, 1827, would have loved to see the construction of the Panama, Suez and Main-Danube Canals. Waterways were the ideal transport routes for timber anyway, but the same applied to coal in the early days of the railroad. Coal had caused the canal boom in England; the Ruhr had been made navigable for coal transportation around 1780. In the early days of the German railroad system, however, coal transport only played a "completely subordinate role" (Fremdling). The Cologne-Minden railroad took no account of existing coal mining towns in its routing. Even on the railroads that had been built specifically for coal transportation, this did not initially take place as expected; even a city like Berlin was still 57 percent supplied with coal by water in 1910.[41]

All of this proves how little - contrary to popular belief - there is to be gained from

a crisis in the supply of wood, there was a compulsion for coal and the railroad. If there really had been a severe shortage of wood everywhere and an urgent need for coal, then the call for canals should have been heard first.

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But little was heard of this, even though the alternative of "canal or railroad" was certainly under discussion. List asserted that once the railroads had been brought to perfection, then "the canals would all be regarded as swamps, and their drying up and filling in as a public improvement". The Main-Danube Canal, named after the Bavarian King Ludwig I, was considered the most sensational project of its time.
"German national enterprise" and as the German gateway to Asia, but - unlike the railroad from Nuremberg to Fürth - it remained a governmental project that was not well received on the stock market. Unlike in England, the railroad enthusiasts did not have to fight against a powerful canal lobby: this only emerged later out of an interest in creating competition for the railroad monopoly.[42]

Alongside the railroad, which has inspired a mountain of enthusiast literature, the *road construction* of the 19th century has received incomparably less attention. Here, too, things were on the move. Whereas in the 18th century the expense of French road construction had had a deterrent effect on Germany, in the early 19th century the cheaper method of rolled ballast ("Macadamization") developed by the American John L. MacAdam was available as a more economically attractive method. Not only the fast locomotive, but also the slow roller marked the new era of transportation.

At times, a race developed within Germany to build roads, as was soon the case with railroad construction. Around 1830, a "road war" broke out between Prussia and some of its neighboring states. The improved roads made it possible for the two-wheeled carts to be replaced by the "large German freight wagon", an innovation of the time, which carried considerably larger loads. A technically inconspicuous innovation such as the steel springs considerably improved the transportation of passengers in the carriages:
"Only since then has driving actually been a pleasure. "[43]

In 1821, the Prussian Postal Councillor Schmücken introduced the express mail service based on the English model, which gave contemporaries the "impression of the most furious speed". Not only did it have a precise timetable, it also kept to it fairly reliably - thanks to system planning, "cours clocks" and penalties for the postilions for being late: it was a real revolution in transportation before the railroad set new standards and turned the post box into a semi-ridiculous symbol of the old days. Shortly after the opening of the first German railroad line (1835), Poppe praised the stagecoaches as a "splendid, extraordinarily useful institution" that had contributed "an incredible amount" "to the progress of human culture and the comfort of life". Treitschke recalled how, shortly before the start of railroad construction, it had seemed to "everyone that the next task was to

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The railroad gave a strong impetus to road construction at a local level, as the advantages of the railroad were only fully realized through feeder roads. The country roads, however, largely lost their importance for long-distance traffic. In 1875, the Prussian state decided to transfer the construction and maintenance of all roads to the provincial associations.[45]

In Germany, the railroad boom marked a turning point and a change of perspective on a scale that is not only explained by economic and technological factors, but also by specifically German driving forces. The experience of the railroad journey inspired Hegelian thought structures in German minds: "This abstraction, this being carried away by the individual by a general power" - said David Friedrich Strauss in 1841 after a journey from Heidelberg to Mannheim - was "quite the same principle that we represent in science". The overwhelming success of the railroad created a certain paradigm of technical progress: it was a progress of radical new beginnings, a progress towards the great machine, the great concentration of power and the networked system - a progress that created its own needs, even if it was initially associated with high risks, both technically and economically.

The danger to life associated with rail travel had been the subject of great attention from the very beginning, ever since the unfortunate Huskisson, one of the strongest supporters of railroad construction in Parliament, had been "most horribly crushed" on the maiden voyage of the Liverpool to Manchester railroad line (1830).[46] But the history of the railroad became an apparent example of the fact that technical risks are best taken courageously and that the fearful end up being ridiculed. Max Maria von Weber vividly described the national character of the railroad system, which was evident in many respects - in his view, not always to the advantage of Germany, where "the rule of dilettantism and subjective opinion" had "cost greater sacrifices" "than the uninitiated believe": greater also in comparison with other countries. Contrary to List's advice, the substructure was based more on the solid English model; in contrast, the "specifically German superstructure system" of the railroad lines was influenced in the early days by Germany's relative abundance of timber and the lack of mass production of iron. "Wooden constructions therefore predominated in buildings and bridges, the superstructure was designed with weaker ironwork to support a lot of wood", similar to the USA at the time. Just as there, costly bridges and tunnels were avoided as far as possible and curves were preferred instead. Level crossings were teeming - a situation that was not overcome until well into the 20th century. The majority of lines were single-track.[47]

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At the same time, labor costs in Germany were relatively low, the completion of the railroads progressed surprisingly quickly and even during construction, surpluses were generated when sections were opened: The financial risk of railroad construction proved to be comparatively low in Germany, especially as there was relatively little competition from good roads or canals. In this respect, there was scope for the generous construction of the railroads; this was used - in accordance with the dominance of the building officials - above all in the furnishing of the station buildings. These became the stone embodiment of the representative and symbolic function of the railroad. In Prussia, this trend reached its bombastic peak in the late 19th century after the nationalization of the railroads.[48]

The impact of railroad construction on industrial development in Germany from the 1940s onwards was striking and impressive, in terms of production figures as well as technology and organization. This was true not only for northern German centers of the iron and engineering industry, but also for Kassel (Henschel), Nuremberg (Cramer-Klett), Munich (Maffei) and Eßlingen. In 1842, the Prussian railroad purchased the first locomotive from German production; from 1847, German locomotives surpassed those imported from England; by 1855, foreign producers were "practically one hundred percent" supplanted by German ones. Within large-scale engineering, locomotives were the earliest German export product.[49] It was a process of dramatic speed and impact, which is all the more astonishing when one recalls the miserable beginnings of German steam engine construction half a century earlier. The contrast shows how differently a technical innovation process proceeds, depending on whether it is imposed from above or whether there is strong and broad interest.

Nevertheless, it remains curious that Germany entered high industrialization with the largest and most complex technology. It would be misleading to draw the general conclusion, as Gerschenkron does, that countries that lagged behind needed the most modern technology, the technology that pushed the system the hardest, as a driving force; in many other countries - starting with Italy - railroad construction did not have the hoped-for *take-off effect.* Even in Saxony's early industrialization, which can still be assigned to the wood and water power era, railroad construction did not function as a leading sector. It could only gain this importance to the full extent for a type of industrialization that was based on coal, mass production of iron and mechanical engineering, which had become an independent industry in its own right. However, the rapid rise of German locomotive and wagon construction, bridge and signaling technology would be inexplicable if Germany had actually advanced so far in its technical level compared to England.

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Germany would have been behind, as was often claimed, and if this backlog had even increased in the first half of the 19th century. The *take-off* effect was possible because there were already numerous, albeit often inconspicuous and stagnant, approaches to mechanical engineering in Germany at the time. Moreover, the technical impact of railroad construction remained limited regionally and sectorally.[50]

Similar to the first phase of electrification, the beginnings of locomotive construction are characterized by Berlin's special role. The conditions in the metropolis were a decisive location factor in the breakthrough of this technology. Locomotive construction brought about the steep rise of the Borsig company from its artisanal beginnings to become "the greatest institute in Germany, perhaps even in Europe", according to the coal merchant Emanuel Friedländer in 1847. Similar to underground coal mining and Bessemer steel production, locomotive construction represented a technical trend towards large-scale operations that had hardly existed until the early 19th century. Of the 729 locomotives in operation on Prussian railroads in 1853, 414 were built by Borsig, followed by Wöhlert, also in Berlin, with 34 locomotives, and finally a number of companies whose production was only a tenth of that of Wöhlert. In 1854, Borsig celebrated its 500th locomotive, and in 1858 its 1,000th, with great fanfare: an apotheosis of the production revolution that fit in with the new age of industrial world exhibitions. The *Gartenlaube* triumphed on the occasion of the thousandth locomotive:
"Prussia is at the forefront of the peaceful war of nations in industry." At that time, Borsig surpassed even American dimensions. By the standards of the time, it was mass production, even if not by those of the 20th century. The large-scale operation was organized according to workshops, and the increase in production roughly correlated with an increase in the number of workers: a sign that the expansion was not associated with major leaps in the degree of mechanization. The time for planned standardization had not yet arrived either; around 1920, when the Deutsche Reichsbahn was founded, there were still around 300 different types of locomotives - a challenge for the rationalizers. The larger German states cultivated their own locomotive designs.[51]

The effect of the railroad on technology and the technical sciences was described in superlative terms from the very beginning. The railroads - to quote Max Maria von Weber once again - "raised all the engineering sciences, the art of measurement, mechanics, statics and dynamics to an extraordinary height so quickly that in the normal course of things it would have taken centuries". As Baader wrote in 1835, it was only through the railways that mechanics became a theory of motion. Before that, according to Baader, "one had actually still

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not a progressive, but only a dragging mechanics". "It was only with the improvement of the railroads that we began to work our way out of the muddy streets. "[52] Until then, all locomotion had largely consisted of overcoming friction, and this was beyond theory at the time. The railroad demonstrated the practical value of an equiva- lent of force and motion and supported a mecha- nism based on it. In the 1840s, a whole series of researchers in Germany, England and France independently arrived at the overarching concept of force, later known as "energy", and the theorem of energy generation in a closed system. "In the history of science, there is no more impressive example of simultaneous discovery," says Thomas S. Kuhn. And it is also a particularly striking example of how technology inspired physical theory. The energy concept did not originate in the study room, even if it did contain a speculative element.

Of course, the railroad had the most direct impact on iron production and mechanical engineering. It accelerated the implementation of the puddling process, which had been slow to catch on in Germany until the 1940s, as puddling, although tried and tested in Carinthia as early as 1793, had for decades been regarded as a quality-reducing expedient for wood-poor regions dependent on hard coal. In many ways, the railroad gave wood a decisive boost as a fuel and building material, even if the huge demand for sleeper timber helped to establish modern wood impregnation and wood research. In 1850, it was agreed in Germany that railroad bridges would no longer be built from wood, which led to the general discrediting of wooden bridges. Wherever the railroad went, iron production based on charcoal found itself in an increasingly critical situation and the coke blast furnace prevailed.

The seamless, unwelded railroad wheel tires, which enabled the railroad to increase its speed beyond 40 km/h, established the fame of the Krupp company and became the company emblem. The special quality of Krupp steel was based on the combination of the traditional crucible steel process with tight large-scale organization. By contrast, German industry did not catch up as quickly in rail production as it did in locomotive and wagon construction: the general lag in rolling technology was noticeable here. Wagon construction played a major role in the rise of the Nuremberg company Cramer-Klett, from which M.A.N. emerged. In terms of production technology, the impetus that this branch of production, which was dependent on series production, gave to the mechanization of woodworking, which otherwise progressed only slowly in Germany, is noteworthy. Cramer-Klett caused a sensation in 1854 with the construction of the Munich Glass Palace,

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Figure 11: Manual transport of a wheel tire at Krupp, 1899. It can be seen how this phase of mechanization partly increased the demands on the physical strength of the workers, especially during transport. The railroad wheel tires made of cast steel without weld seams, which withstood extreme stresses, established the prestige of the Krupp company even before the carriages; the company emblem of the three rings alludes to them.

which the company completed in a hundred days; the London Glass Palace was not surpassed in size, but in speed of construction and economy of materials.[53]

The railroads were soon followed by telegraphs, which were often laid along railroad lines; however, telegraphy was slow to conquer the railroad signaling system. In 1870, when the war disrupted timetables, Siemens developed a system for automatically blocking the signals that cleared a section of track; the company temporarily became a "signal construction company". One or two decades later, the electrification of locomotives even seemed imminent; however, the breakthrough of electricity was still half a century away.[54]

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Similar to Bismarck's victories, the dimensions of railroad construction threw liberal principles into confusion. Actually, the liberals should have advocated that the state should stay out of railroad construction; sometimes they did so - especially in the Prussian constitutional conflict of the 1860s - but incidentally, it was precisely the Prussian liberals who vehemently pushed for state railroads early on. Germany lacked the masses of risk capital that would have been necessary to rapidly advance private railroad construction; a broad consensus therefore emerged in favor of state railroad construction. Even if the state was reluctant at times, there was never really a "liberal era" in the railroad issue; the nationalization of the Prussian railroads after 1871 was preceded by an era of "creeping nationalization". In 1901, Octavio von Zedlitz and Neukirch, former president of the Seehandlung, was able to state in retrospect that the nationalization of the railroads was "the most brilliant financial transaction the Prussian state has ever made".

In the following period, under the influence of agricultural interests, "the absolute emphasis" in the construction of new lines was "on supplying the Prussian East with branch lines" and on the construction of small railways in general. East Germany was given one of the densest small railway networks in the empire. Efforts were made to make small railway construction cheaper by lowering construction standards and allowing narrow-gauge railroads; however, the railroad could only be miniaturized in a commercially profitable way to a limited extent. The financial success of the nationalization of the long-distance railroads was not repeated, and the economic upturn hoped for in the East from railroad construction also failed to materialize.

The expansion of the main lines stagnated; Borsig locomotive construction fell into a serious crisis. To a limited extent, efforts were made to increase speed - for example with the introduction of the D-trains (1892); however, the prevailing opinion was that the existing superstructure did not permit an increase in speed far in excess of 100 km/h. A "cautious approach" was regarded as the "duty of the leading technicians in the state railroad administration". Around 1898, a senior civil engineer declared: "Our time is already nervous and hasty enough; we should not encourage this by increasing speeds even further." The complaints about "modern nervousness", which had grown into a veritable flood since the 1880s, showed their effect.[55]

According to VDI board member Richard Peters, the tradition of state engineering resulted in the "abnormal and unjust fact" that "all top technical positions on the state railroads are only held by civil servants, while the heads of engineering are not allowed to join the directorate despite their important sphere of activity" - at least this was the case in Prussia in 1867. Metropolitan railroads

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courtyards were given magnificent historicist buildings: The railroad was at the forefront of architectural ambition. However, until after the First World War, railroad construction and maintenance of the lines were almost entirely carried out by hand.[56]

In Germany in the early 20th century - more so than in Western Europe and the USA - the expansion of mass transportation, especially local public transport, was still at the forefront of general interest: a not at all unreasonable priority, especially from today's perspective, as large German cities were often built more densely than English or American ones. Werner Sombart predicted that the "last epoch" of transportation, in which we already find ourselves, would "end with a railroad running in front of every house. The development of secondary, tertiary, etc. railways, a system of narrow-gauge railways, etc. Railroad construction, a system of narrow-gauge railroads in a word." If this had been the case, there would have been no public interest in opening up the roads to the automobile in the first place. In 1895, the Farmers' Union called for a network of narrow-gauge railways that would cover the flat countryside so densely that no point would be further than half a German mile (3.7 kilometers) from the nearest railroad station.[57] In Prussia, this would have required an expansion of around 56,000 kilometers, ten times the previous network!

Urban public transport benefited from the wave of electrification at the end of the 19th century. *Streetcars* were the easiest way to demonstrate the benefits of electric propulsion, and these in turn provided the impetus for the establishment of "power stations" in many cities. From the outset, they were planned as promising urban networks. Even at a time when, from the perspective of the automobile, the streetcar was already a laughing stock and an obstacle to traffic, Werner Hegemann called its invention "at least as ingenious" as that of Gothic cathedral construction technology. In 1881, the world's first streetcar built by Siemens ran in Berlin, but the Berlin city council remained opposed to electric overhead lines until 1898. It was only when the streetcar had become established in American cities and returned to Germany around 1890 that it spread rapidly. By 1898, there were already trams in 69 cities. As in other European countries, many complaints were directed against the disruption of the familiar street scene by the overhead lines; nevertheless, acceptance in Germany was soon higher than in Western Europe. Urban rail networks with their own tracks, such as the Berlin Stadtbahn or the Wuppertal suspension railroad, were regarded internationally as exemplary.[58] The question of which transport technology was adapted to German conditions was hotly debated here with practical effect, unlike the car, whose implementation seemed to proceed like a natural process and condemned critics to impotent rage.

Today, *bicycles and cars* seem to be the epitome of transportation alternatives.

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However, around the turn of the century, it was not uncommon for the one and the an

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other means of transportation as the embodiment of modern frenzy. One can see the irony of history in the fact that, historically speaking, the bicycle acted as an introduction to this new individual speed addiction, which was immediately given its hard drug in the form of the automobile. As ambitious and inexperienced cyclists tended to overdo it with their strength, it was initially questionable whether cycling was healthy; but soon the velocipede was also applauded by many doctors. Cycling and motoring began as a sport and were promoted by a sporting camaraderie of athletes: a novelty in the diffusion of technology. The two new means of individual transportation also made their mark in the history of advertising; they were promoted through competitions and technology-specific ad hoc philosophies. Even a historian like Hans Delbrück, a chief ideologue of Wilhelmine "world politics", went so far as to prophesy that the workers' bicycle would solve the social question and that the "future of the people" lay "in the velocipede".

However, the bicycle was probably the most epochal of all in the novel experience of a unity of technology and body that was created by pedaling. People experienced what they could only have guessed at on the draisine and what no scientist could have foreseen: that on a vehicle on which you fall over when standing, you gain a secure balance through the movement, and even more: a full feeling of your own strength, indeed of unknown forces, a new deep calm at a whizzing pace! All in all, an elementary experience

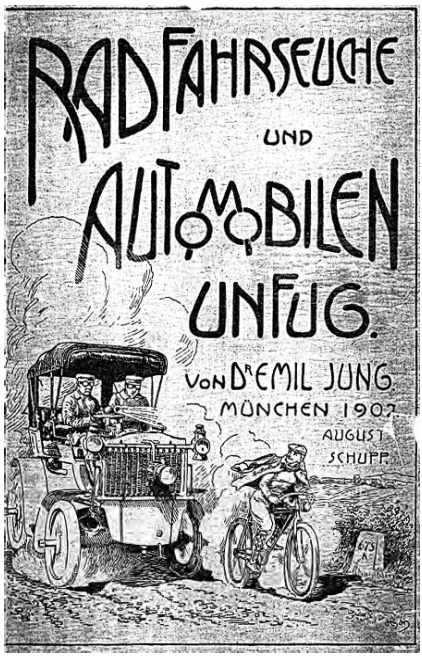

Figure 12: "Radfahrseuche und Automobileunfug", pamphlet by Dr. Emil Jung from 1907.
"gentle" alternative to the automobile, but in the same way embodies the hectic pace generated by the new traffic technology, which deprives people of peace and quiet. In fact, cycling often began as a racing sport. The book, apparently written by a Christian, bears the subtitle:
"A contribution to the right to rest". The illustrator of the cover picture seems to secretly sympathize with the cyclist: The cyclist cheerfully overtakes the stiff and stiffly seated motorists, who lose their human face due to the protective goggles.

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The experience of modernity. No technological imagination had prepared it: Until around 1900, technology literature, constrained by energy blinkers, did not take this vehicle, powered neither by steam nor electricity, seriously. There is no doubt that it all started with the experience. However, it was elevated by the contemporary philosophies of Art Nouveau and life reform - and by the allure of the new. Today's cyclists no longer enjoy the boundless exhilaration of the cyclists of the turn of the century. The bicycle, the price of which fell to a tenth in a decade at the turn of the century - from 200 to 300 Reichsmarks to 20 to 30 Reichsmarks - demonstrated the possibilities of mass production more impressively than almost any other product up to that time, long before this became established in the automobile industry.[59] In technical terms, but even more so in psychological terms, the bicycle was an origin of the car, and even of the early flying machines. Carl Benz described how the idea of the automobile arose from his experience of the velocipede. Although the first wheel - the draisine, which was still made almost entirely of wood - was built around 1813 by the retired Baden forester Carl von Drais, and although the first automobiles were also built in Germany, the bicycle initially spread as an English technology and the car as a French one.[60] It was not until the era of mass-produced steel, and even more so colonial rubber, that it became a convenient means of mass transportation.

The German gap to France is particularly noticeable when it comes to cars, which has only been caught up with since around 1960. If one assumes that driving a car is not a natural human instinct, it is a pseudo-problem and the French advance needs to be explained. Resistance to early automobilism was widespread not only in Germany, but also in Western Europe. It was more effective at local level than at higher authorities: one reason why centralist France had a worse immune system against car fever than the German Empire. Here, the Emperor himself and the Emperor's brother Prince Henry, the patron of motor racing - still an enthusiastic cyclist around 1900 - were the car lobby's strongest trump cards. Western Europe's lead in bicycles and cars can be partly explained by the genesis of the sports and record-breaking movement there. The Germans, who were still considered slower and more sedate, had an upper class whose status symbols were, by and large, more closely tied to the feudal-aristocratic world of horses and equipages than those of the Western European elites. In any case, the French upper class of the Belle Epoque was more likely to be the type of autonarren than the German: the type of wealthy idler who loved sports and shows.

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The buzzword "speed" came over from France around 1900. Carl Benz thought 50 km/h was fast enough and wanted the car to blend in with existing road traffic and not compete with express trains; but he resisted car racing in vain. As the example of the like-minded Henry Ford shows, the preference for simplicity and solidity over high-bred fast starters could have been turned into a successful technical strategy. The better road network in France does not provide a sufficient explanation for the early automobile boom there; in the USA, Ford cars became a mass product on much poorer roads. However, it was in France that the marketing needed to turn car production into a business flourished best. Back then, France was the "land of advertising", even more so than the USA.[61]

Initially, the fuel supply for German automobiles came from domestic resources: benzene, the mother substance of organic chemistry, which - propagated by Prince Heinrich - had been used as a car fuel since 1904, was a by-product of gas works and coking plants, and production at the time far exceeded demand.[62] However, the fact that the car and even more so the bicycle contradicted the technological paradigms prevailing in Germany at the time, which were inspired by the steam engine and electricity, had an inhibiting effect. As Otto Kammerer, mechanical engineering teacher at the Berlin Technical University, put it in 1910:

"Power generation and power distribution are the two most important basic principles of modern technology; the combination of these two ideas forms the actual basis for the progress of machine technology in the last decade. "[63]

The logic of this idea most likely led to electric mass transportation, and one must ask why this path was not taken more consistently. Oskar von Miller did not give the automobile its own space in the Deutsches Museum he founded and preferred the streetcar for his person. However, the car had the attraction of individually controlled motorization from the very beginning; the fascination with the automobile began early on, especially among the social elites. In the "electric age" proclaimed around 1900, the electric motor initially appeared to be the

"most obvious and technically simplest" drive. Siemens and even Porsche backed the noiseless and odorless electric car, which was praised by the magazine *Prometheus* in 1911 as "decidedly the most ideal motor vehicle from a hygienic point of view". But the heavy batteries limited the electric car's driving performance and speed increase; for the motoring community, which was enthusiastic about sport and hunting, this vehicle had no appeal. The further development of batteries came to a standstill: This sealed the fate of the electric car for the time being.

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Figure 13: Oskar von Miller and Henry Ford at the Deutsches Museum, 1930: The founding father of the Deutsches Museum with the habitus of a native Bavarian face to face with the most American of all Americans, who embodied American technology like no other. He gave Miller a Ford car as a gift, but Miller put it in his museum without giving the automobile its own section and continued on to the museum by streetcar.

All the basic problems of modern car traffic could already be recognized in outline in the early days of automobilism, indeed they provoked more violent reactions than one or two generations later; for before 1914, the broad mass of the population did not yet identify with the car and was not yet hardened against road casualties; the sight of run-over passengers was still a reminder of the gruesome punishment of being wheeled. A former head of development at Daimler-Benz recently rightly asked whether the car "would not simply have been banned" if technology assessment had been carried out at an early stage.[64] This should be an argument against *technology assessment*, but there is another way of looking at it. However, unlike the railroad, the car, the first motorized means of individual transport, was increasingly seen as a matter of individual choice, not of politics. In general, technical development around 1900 was less and less understood as a field of political decision-making, even though it was still of growing political importance and by no means followed a purely technical logic - especially not in the time of the world wars. But the new technology, still comparatively vivid in the 19th century

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and tangible, became an increasingly confusing and opaque realm in the 20th century.

3. "Cheap and bad" - world exhibitions and technological nationalism

The epochal watershed around the middle of the 19th century manifested itself particularly picturesquely in the London World's Fair of 1851 and the subsequent series of other world's fairs that shaped the public perception of technology in the second half of the century. Towards the end of the century, the series of international electricity exhibitions brought a final culmination to this era of major technical celebrations. In England, which until then had tended to be more reticent about large exhibitions than France, which was keen to exhibit, the overture of the world's fairs symbolized the turning point from shielding against industrial espionage to showcasing one's own technical achievements, from protectionism to free trade and also from the deep social tensions of the first half of the century to socio-political optimism. From then on, it was part of the style of these exhibitions that technology was presented in a broad panorama of products of art and culture and was itself presented as a cultural achievement and a world of wonders. Technology as a public event, as part of the festive culture, as a national symbol and arena of competition between nations: All this was only possible at a certain technological level, at which technology was no longer a mere individual thing with a purely practical purpose, but became an entire panopticon of modernity. In Germany, the industrial exhibition system first gained momentum with the Berlin Trade Exhibition of 1844.

> At the world exhibitions, the exhibits were almost always organized by country.

The exhibitions were organized according to the principles of the exhibition; there was no attempt to replace this organizational principle with a fact-oriented one. In this way, the exhibitions staged an international competition of industrial and applied arts excellence and provided inexhaustible material for commentary on the national profiles presented there, which had never before been presented so impressively.[66] At the same time, the world exhibitions educated people to view technology not only from the perspective of practical usefulness, but also in terms of prestige. Through the exhibitions, top achievements received attention that went far beyond their current economic value, but influenced the formation of opinion in industry and technology.

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Krupp's cast steel cannons and steel blocks were an eye-catcher in the German departments from the very beginning: even at a time when nobody wanted to buy the Krupp cannons. In addition to Krupp, the Siemens & Halske pointer telegraph received the highest prize medal in 1851: an award in a situation in which the company, still struggling for its existence, had lost the support of the Prussian government. The Thonet chairs, which introduced the hot bending process to furniture production, attracted "special attention" in London even before they had achieved their major breakthrough on the market. The New York Crystal Palace Exhibition of 1853 made the "American system" of mechanized mass production a household name for the first time, although at the time it was still more of an ideal than a widespread and economically satisfactory production method. Since the London World's Fair of 1862, the colorfulness of German tar chemistry had been a constantly new attraction, creating the impression that chemistry was already a leading sector of the German economy - a suggestion that was far ahead of the statistical reality: even in the final years before 1914, only 2.3 percent of German industrial production was attributable to chemistry.[67] At the Paris World Exhibition of 1867, the Otto engine was awarded a gold medal; thanks to its twice as high efficiency, it was preferred to the Le Noir engine: The sensational event gave it a significance that had no economic basis at the time. Machine tools from the Zimmermann company in Chemnitz achieved the highest prices in London in 1862 and Paris in 1867, although the machine tool industry at that time mainly produced for the local market and only became a leading German export industry in the 20th century. In 1867, Voelter's paper ranges made from groundwood pulp won a silver medal at a time when groundwood pulp paper still had to fight against strong and by no means unfounded prejudices in Germany. The "light miracle" of arc lamps at the Paris World's Fair in 1878 fascinated the public at a time when experts were still skeptical about electric light. The "high-speed steel", which until then had been considered an American bluff by experts, achieved its breakthrough in Europe with the demonstration of the process at the Paris World's Fair in 1900.[68]

The first world exhibition of electrical engineering, held in Paris in 1881, demonstrated

the European leadership position of Siemens, after France had previously been the leader in electricity. The Chicago World's Fair of 1893 filled German technicians with a Wilhelmine sense of superiority: German technology now seemed to be at the forefront of Europe, although Reuleaux, again in the role of Cassandra, pointed out that Germany lagged behind American machine tools in terms of precision.

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Figure 14: Exhibition stand of Berliner Maschinenbau AG at the Frankfurt International Electrotechnical Exhibition of 1891. The electrical industry, which first had to create its own market, was one of the pioneers of modern advertising. It made use of the Art Nouveau style that was emerging at the time and worked not only with lighting effects but also with erotic stimuli. On the left is an "antique dancer" holding a garland of glowing lights, on the right a "juggler" balancing an electric lamp on the tip of her foot: This was pushing the boundaries of decency at the time. The new world of electric light as a magical world with an erotic touch!

But after 1900, it was possible to observe at the world exhibitions how German machine tool construction caught up with and in some cases overtook American machine tool construction.[69]

Soon after 1900, world exhibitions lost their importance as a medium of technical progress. The idea that the exhibitions had "outlived their usefulness" became a common topos, especially in Germany. The unpeaceful competition between nations became technologically even more fascinating than the -

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The tendency for technology to develop a growing symbolic, power and prestige value in addition to its utility value - not only for nations but also for private consumers - continued in the 20th century, as evidenced by the rise of advertising.

To what extent was the national industrial culture celebrated at the world's fairs a mere show, a reflection of the nationalist climate of the time, and to what extent did it contain economic and technical substance? The journalism of the time loved to attribute the adoption of technical innovations to world fair experiences; in this respect, an exaggerated impression of the importance of this exhibition can arise. From a sober point of view, information about technical innovations could have been obtained earlier and better from the trade journals.[71] But the "technology transfer" did not take place through factual information, but through concrete visualization and the suggestion of international trends. The world exhibitions did indeed play a key role here.

One particularly clear effect of these exhibitions was that nations were encouraged to identify themselves more strongly than before with certain cutting-edge technologies that could be showcased internationally. A process of "nationalization" can indeed be observed in these technologies and the associated industrial sectors during the second half of the 19th century, particularly evident in companies such as Krupp or Siemens, which around 1850 were in a tense relationship with Prussian administrative leaders and at times could only keep their heads above water with Russian orders, but later entered into an increasingly close and ultimately vital relationship with the Imperial German administration. They became pacemakers in the profiling of German technology within a national framework. Around 1865, Werner Siemens, as a representative for Solingen-Remscheid, fought against the "suicidal habit of marketing German products as English, French or even American". He clashed with the steelware manufacturers in his constituency, who wanted to stick to this habit; the "Made in Germany" designation, which was enforced by England in 1887, was particularly aimed at Solingen. At that time, however, "Made in Germany" became part of German corporate advertising.[72]

In the past, manufacturers of top-quality products were typically far-
trade-oriented, the hugely expanding national domestic market created new conditions here. The battle over patent law in the 1970s was also fought with ideas of "national" technology. While the role of the state in technical development tended to decline until the sixties, railroad construction, electricity and armaments gave rise to a "national" technology.

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This was a trend that particularly affected industries that were considered to be technically advanced. And it was always the state that urged industry to take part in the world's fairs from the point of view of national prestige; for industry, presenting itself there was not least about cultivating its image vis-à-vis its own government.[73]

For the majority of German industry, however, the exhibitions as such were of little interest from a purely business perspective. Many German manufacturers initially saw the London Exhibition of 1851 as a kind of trade fair and did not understand its representational and image function. As the official German exhibition report criticized, the ironmongery manufacturers appeared in London "only with their currents goods" and used "nothing in the way of tasteful arrangement and staffage"; "and so the German Ironmongery Exhibition did indeed resemble the junk store of a busy ironmonger". The most renowned traditional German technology, the mining industry of the Harz and Ore Mountains, was not represented.[74]

In the two decades following the founding of the Reich, of all times, there was a veritable defiant reaction in large parts of German industry against the "Exhibition epidemic" (Siemens), with the remarkable result that the world exhibition planned for Berlin in 1885 did not take place and no world exhibition was ever held in Germany until the Hanover Expo in 2000. Instead, in 1879/81 there were two World's Fairs in Australia in quick succession, in Sydney and Melbourne, even though this continent had less than two million white inhabitants at the time and could only be reached at horrendous cost. It was a race to the ends of the earth, the economic irrationality of which was clearly evident; but the Reich government managed to achieve a spectacular German appearance in Melbourne.[75]

Machines were not at the center of the world's fairs from the very beginning; they only became a main attraction in Paris in 1867, and even then the mechanical engineering teacher Reuleaux, the German preceptor of the exhibitions, complained that machines were basically not ideal objects for exhibitions of this kind. London 1851 was not only a triumph of British technology, but also - as was generally recognized - a victory of the "glorious art industry" of the Indians, who had been degraded to a colonial people, over European factory goods. The old advanced civilizations of the later "Third World" still appeared to be a wonder world, not an "underdeveloped" underworld.

The trend towards cheap mass production ran counter to the overall tendency of the exhibitions, as they primarily cultivated the exquisite and unique. Instead, they encouraged the founding of museums of decorative arts. But the second half of the 19th century did not acquire its specific character

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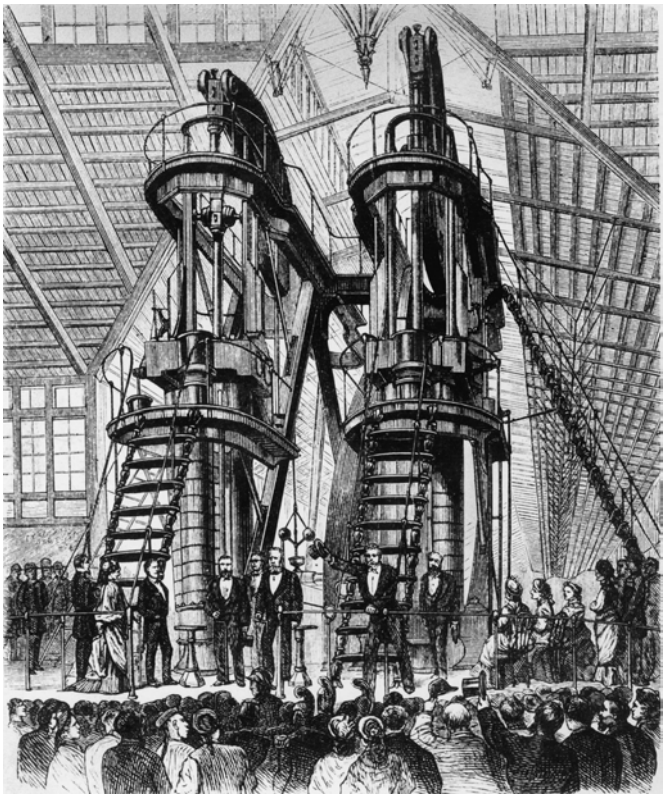

Figure 15: Opening of the World's Fair in Philadelphia in 1876: President Grant and Dom Pedro II, Emperor of Brazil, set a towering Corliss steam engine in motion. The steam engine is still regarded as the pinnacle of technical progress! Over eight miles of transmissions, this machine set hundreds of other machines in motion: all at once, the giant exhibition came to life. However, it was the many small American steam engines in particular that attracted the interest of German engineers.

This was due not only to progress towards mass production and the replacement of people by machines, but also to counter-reactions and efforts to incorporate the technology into traditional culture. Significantly, the advantage of photography over the daguerreotype in the mid-19th century was seen in the fact that it was possible to retouch faces and adapt them to idealized portraits, whereas this was not the case with the daguerreotype.[76]

The Philadelphia World's Fair (1876), which was held as a centenary celebration of the American Declaration of Independence and opened with a march composed especially for the occasion by Richard Wagner (although not even appreciated by Wagnerians), provided the backdrop for the famous

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polemic by the German judge Franz Reuleaux, which immediately became a catchphrase and the trigger for fierce press feuds: Germany's industry, as presented in Philadelphia, was producing according to the "basic principle" "cheap and bad".[77] Reuleaux was allegedly reflecting the opinion of the German-American press in particular, who were furiously disappointed with the way their old homeland was presenting itself in the new world. At the time, his letter from Philadelphia was greeted with heated criticism in the German press; the accusation of sweeping injustice and damage to German interests was all too obvious. Later, however, this affront was seen as a fruitful challenge that had brought about an epochal shift in German industry from price competition to quality competition, from imitation to originality, and had led to the labelling of German goods with the "Made in Germany" label enforced by the English *Merchandise Marks Act* of 1887, which was still based on the "cheap-and-bad" image of German goods, becoming a mark of quality: the German success story gone bad![78]

While it is certainly not possible to attribute a turning point in the entire culture of production technology to press polemics alone, the Reuleaux controversy nevertheless sheds light on the field of tension in which the development of German technology was taking place at the time. "Cheap and bad" was certainly unfair as a blanket judgment. It was first and foremost a deliberate provocation out of anger at the fact that a large part of German industry lacked a sense of glamorous self-presentation to the world and also a lack of respect for the achievements of the scientifically trained engineers who were pushing upwards: From Reuleaux's point of view, the one shortcoming was related to the other. His criticism reflected the situation after the start-up crash, which severely affected the career opportunities of engineers; it was devastating for the prospects of academic technicians when industry sought a way out of the crisis primarily in cost reduction and cheap products. "Cheap and bad" applied to a part of the German mechanical engineering industry at the time, which still sold its products by weight and about which evil tongues blasphemed that it could not dare to exhibit its machines abroad anywhere outside Russia. The verdict also applied to pre-industrial areas of the German economy: to small master craftsmen who tried to compete with the machines by producing slingshots instead of skillfully specializing in products that could not be manufactured by machine.[79]

Reuleaux was not only a luminary of mechanical engineering, but also a a lover of the arts and crafts, which he often praised more than the achievements of industry in his exhibition reports. He, who had banished everything technical and empirical from technology in favor of pure theory, was a

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and therefore rejected the establishment of laboratories at technical colleges, was committed to the artistic elevation of craftsmanship: he thus embodied an ambivalence characteristic of the time. Historicism, with its flourishes, gave new impetus to the arts and crafts. When Reuleaux condemned price competition and spoke of price and quality competition as irreconcilable alternatives, he was seemingly following the logic of the old craftsmanship; mechanization, on the other hand, made it possible to combine both types of competition. But he found support from Werner von Siemens, who praised his courage; in the situation of 1876, "cheap and bad" served as an argument for improved patent protection, the main issue for German technicians at the time, and was thus used by Siemens in a letter to Bismarck. The perniciousness of price competition was a standard memento of cartel supporters and protective tariff advocates; Wilhelm von Kardorff, the leader of the new protective tariff alliance, hastened to outdo Reuleaux in polemics. But the social democratic leader August Bebel also declared the "principle of 'cheap and bad'" to be a flaw of capitalism, which would be overcome under socialism by a higher standard of living for the broad masses.[80] Reuleaux received approval from such different sides! It would be misleading to take the *letter from Philadelphia* merely as a reflection of the level of German technology at the time.

The official German report on the London exhibition of
In 1851, he believed he could state that "Germany had entered the second period of development in machine tool construction", "in which the mere copying of foreign patterns was abandoned and instead the independent development of original machines came to the fore". But was it really the case that there was a lawful "development" from imitation to originality - was imitation a contemptible manner that had to be overcome once and for all in the interests of increasing profits and national prestige?[81] Artistic originality is not a sensible ideal for technology. Until the 20th century, the success of the German machine tool industry was based on the fact that it was able to learn from its American competitors better than its British counterparts.

Of all the individual inventions, the innovation that probably had the greatest significance for German industry in the late 19th century was the appropriation of the Thomas process invented in England, with which the Lorraine ore deposits annexed in 1871 could be used in the first place and German heavy industry gained the cheap domestic ore base that subsequently became its "key to success", especially vis-à-vis England. The technological path that was particularly adapted to German conditions, which was not initially recognized as such, consisted of using the special

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This was, economically speaking, much more important for German heavy industry than Krupp's giant cannons and crucible steel ingots, which became a showpiece of German self-portrayal to the world. In the 20th century, the rise of Japan showed in exemplary fashion that creative imitation and adaptation in technology are far more useful than striving for originality at any price and that the "Faustian urge" for technical success is not nearly as important as it was often attributed to it in Germany.

4. Abstraction and authority - on the role of science

The question of what the scientification of technology is all about is a key problem in determining the "German path" in technology, because the consensus is that Germany played a pioneering role in this process of scientification (cf. chapter 1.4). In 1870, the British magazine *The Engineer went* into raptures when describing the university laboratories of Berlin, Leipzig and Bonn and was reminded of Bacon's vision of New Atlantis. Ernest E. Williams, whose bestseller *Made in Germany* (1896) made the "German danger" the talk of the British town, considered it a foregone conclusion that "Germany, by transferring (scientific) chemistry to the practical field, had conquered the world", in keeping with the tenor of German chemistry's nationalistic self-portrayal. The
The "brilliant system" of German technical training was to the English system as electric light is to the oil lamp; the German technical universities were true "palaces" with "lavishly" equipped laboratories. In the Bayer laboratory in Elberfeld, "no fewer than sixty trained chemists are paid a decent salary for what the Englishman
'Doing nothing', but the German calls it 'research'".[83]

So is the scientific basis of Germany's industrial rise one of the best-documented facts in the history of technology? But the scientificization of technology was already being emphatically proclaimed at a time when, in reality, there could be no question of it. The official report on the Bavarian Industrial Exhibition of 1822 believed it could state:

"Daily experience shows as clear as day that there is hardly a trade today in which ordinary craftsmanship is still sufficient. Anyone who wants to rise above the ordinary also needs to apply knowledge in many ways.

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knowledge that gives his undertakings certainty and ensures greater success."

This is how the "Principles for the Promotion of Trade" began. The application of science was therefore worthy of promotion - at a time when the practical benefits of science in the vast majority of areas of technology were nothing less than "as clear as daylight". However, it can be seen that there was an early tendency in Germany in particular to expect everything from science for technology per se, to attribute all the successes of technology to the application of science and to take scientificity as an indication of solidity and higher value, while in England the opposite tendency was to trivialize the share of theoretical knowledge in innovations and to attribute inventions to practical testing.[84]

The idea that technology had its reliable foundation in science was already an outdated topos in the late 19th century, the real content of which needs to be examined. It can certainly be accepted in the sense that leading technicians increasingly required scientific training and a researching intelligence. In most cases, however, the thesis of scientification means more: that technical innovations increasingly stem from scientific theories, that science becomes the driving force behind technology and that the two areas merge ever more closely. Liebig proclaimed such ideas with great emphasis as early as 1840, in the midst of a world still producing almost entirely on the basis of manual experience. He claimed that the discovery of oxygen had paved the way for "countless factories and industries, steam engines and railroads". "The material prosperity of nations" had been "increased tenfold as a result". He advised his students to get rid of all practical inclinations in their studies and devote themselves entirely to solving purely scientific questions - then success in practice would be all the more brilliant, and would often come promptly:

"I know many of them who are now at the head of soda, sulphuric acid, sugar, blood lye salt factories, dye works and other trades; without ever having had anything to do with it, they were perfectly familiar with the manufacturing process in the first half hour, and the next brought a lot of the most useful improvements."

In fact, thanks to his knowledge of the chemical formulas, Liebig was able to help a Berlinerblau manufacturer in Glasgow to simplify the production of blood lye salt. By far the best known and most lucrative, however, was "Liebig's meat extract", which made the huge cattle herds of South America usable for the German national diet even before the era of refrigerated ships, but did not exactly reflect the latest state of chemical theory.

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was sprouting. Liebig's propaganda for scientific chemistry seems colossally exaggerated when one considers the largely non-scientific practice in the "chemical" factories of the time, which by later standards were wretched poison kitchens, and when one considers that the immediate practical benefit of Liebig's teachings was often doubtful.[85] And yet many practitioners in industry put up with these claims by scientists, since science had an image value for them and the universities provided them with subcontracting services at state expense.

All the more reason to pay attention to what was understood by "science" in each case and what associations were linked to this term. In 19th century French technology, "scientification" meant above all mathematization; but the dominance of mathematics was fought for by leading German scientists and technicians. As Carl Duisberg, who embodied the rise of chemical science to industrial power like no other, emphasized:
"Scientific certainty took the place of the chance successes of earlier years", "scientific", associated with "certainty", was primarily aimed at regulated, systematized procedures. For Duisberg, the organizational fanatic, "science" always meant order, discipline, precisely defined and controlled procedures. Similarly for Walther Rathenau, who reminded the German Civil Service Association in 1920 that "Germany's strength lay in the fact that it based its entire economy on science, because technology is nothing other than applied science". For him, the scientificization of the production process at that time was associated with standardization and typification, with a large-scale collaborative economy and division of labour. A "unified will, a scientific spirit" should fundamentally solve the "problem of reunifying the stages of production".[86]

Scientificization was proclaimed with particular emphasis at a time when *"organization" was* the magic word, *"system"* was the watchword and organizational achievements were regarded as a special talent of German industry. Above all, industry needed the authoritative element of science; science legitimized hierarchy and control of manual labour, it justified rationalization and reorganization.[87] The natural sciences were not necessarily brought closer to technology in the 19th century out of internal logic. The rise of physics and chemistry also strengthened the esprit de corps, the internal structure of these disciplines. The increase in theory and the drastically increased level of abstraction, the technical jargon that was increasingly separated from everyday language, made the natural sciences in some ways more remote from practice than they had been at the time.

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as they still largely corresponded to the sensory view and used the general language of education.[88]

Behind the often stereotypical emphasis on the scientific basis of technology were obvious interests; mostly the status ambitions of the rising class of educated engineers, who had been forming as a professional group since the middle of the century and until the late 19th century were primarily concerned with setting themselves apart from the craftsmen and advancing into the educated middle classes. It was only when the academic status of the engineer was secured that the other tendency to distinguish the engineer as a man of practical experience from the scientific theorists became stronger. For many German engineers of the 19th century, "empiricism" meant "technical narrowness", "empiricist" was almost a dirty word; Redtenbacher spoke of the "wishy-washiness of the empiricists", which had become "disgusting" to him. In 1877, Max Maria von Weber remarked that "the best and clearest thinkers" among the technicians had recognized that it was "above all important to weaken the memory of the supposed origin of technology from the craft and the prejudice that regarded it only as a scientifically draped profession among the leading classes of state and social life".[89]

The disregard for technology by the humanist educational elites did indeed sometimes take on provocative forms. The Prussian Minister of Culture, Falk, denied the scientific capability of technology in principle. Treitschke called his fellow chemists "apothecaries and dung drivers", and for Mommsen, the natural sciences were "barbarians you can train a hunting dog on".[90] Such prejudices took on practical significance in the battles over the Patent Act and the right to promote technical universities. However, it was not only about such specific points of contention, but also about the inclusion of academic engineers in the educated middle class in general. The relationship between leading chemists and technicians and the German educational tradition was ambivalent in typical cases; the dichotomy could even develop into a love-hate relationship. Liebig fought furiously against the natural philosophy of Goethe's time, but proclaimed his own thoroughly speculative natural philosophy when he claimed to restore the cycle of nature with chemical fertilization. He also wanted to use chemistry to fathom "the nature of the life force"; and it was precisely such propositions that inspired the young Duisberg for chemistry. The natural scientists and engineers felt that the intellectual claim to dominance of philosophy and philology was presumptuous; but the striving for the idea and the great system that originated in speculation also entered into technology, albeit in tension with the increasing specialization. Reuleaux searched for the "true formative laws of the machine"; he asked about the *essence* of the machine and found

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This in the movement, not in the production of useful things. Ostwald believed that the tyranny of the philologists at secondary schools was stifling the best forces of the youth; but he took the "risk" around 1900,
"to bring the infamous name of natural philosophy back to honor," even though he considered the old natural philosophy a national disgrace.[91]

Contrary to a widespread assumption, the scientification of technician training did not simply result from the growing complexity of technology, but required some effort to legitimize it.[92] It created a social divide between engineers and master craftsmen that could not always be justified by the practical requirements of production. There is no simple causal relationship between the history of technology and the social history of technicians.

From the 1860s onwards, the importance of science for technology was particularly determined by the disputes surrounding the *Patent Act*, which was finally passed in 1876, and the subsequent patent disputes. The fierceness of the disputes was itself the result of an image of technology that believed in science, according to which "inventions", new ideas and intellectual achievements were the key to technical success. This meant that the patent system could be played up as the lifeblood of German industry and its importance greatly overestimated. On the other hand, the more it was recognized that the scientific nature of inventions in general also depended crucially on practical implementation up to production maturity, the more the patent system receded into the background as a topic of discussion in industry.

Werner von Siemens had been one of the initiators of the Patent Act; Emil Rathenau, on the other hand, was hardly interested in patenting his own innovations: In the construction of power stations, experience was everything and individual ideas meant little. Even in the chemical industry, which was particularly passionate about patent battles, the situation was similar. When the patents of German chemistry were confiscated by the Allies during the First World War, Du Pont had to realize that "no normal chemist can work with these patents. They were written for Germans who had spent their lives in the paint industry. "[93] This applied above all to patents relating to production processes. More valuable, on the other hand, were patents on specific products, for example in the pharmaceutical industry.

Since Beuth's time, Prussian trade supervision had a tradition of being hostile to patents, which was supported by numerous chambers of commerce: Patents were seen as a violation of freedom of trade and as an obstacle to the progress of an industry reliant on the adoption of innovations from abroad. In the 1960s, there were even increasing efforts to abolish the existing, increasingly restrictive patent protection altogether.

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Bismarck himself submitted a motion to this effect to the Reichstag of the North German Confederation in 1868. German industry profited from the inadequate patent law as long as it was more of a taker than a giver when it came to technical innovations abroad (similar to the way the Swiss pharmaceutical industry later flourished due to "patent robbery" from the point of view of its German competitors). The Prussian patent office even denied Bessemer patent protection on the grounds that no one could be prevented from blowing air through liquid iron; but Krupp also suffered from Prussian hostility to patents, and even the famous alizarin synthesis (1869) was not deemed worthy of a patent.

The fierce battle that had been waged since the 1960s for a change in patent policy and for a uniform German patent law indicated that companies that made technical innovations their business were increasingly setting the tone in the economy. The success of patent supporters was aided by the victory of protectionist forces in the economic depression of the 1970s, even if patent protection as such did not contain any protective tendencies, but rather made protective tariffs unnecessary for the protected products.[94]

In many respects, the battle over the Patent Act consolidated the alliance between industry and science. The belief that the success of German industry was essentially based on science was necessary to make the protection of intellectual property in technology appear to be a national task. When the Patent Act was passed, scientists were needed to formulate patents and defend them before the patent court. Under the protection of the patent, the publication of inventions was possible: the previously existing conflict of interests between industry, which was concerned with secrecy, and scientists interested in publication, the "dilemma between factory secrecy and disclosure", was thus alleviated. However, in contrast to American patent law, German patent law permitted the transfer of patents not only to individuals, but also to companies: Through this possibility, for which Siemens had fought bitterly, it created the legal framework for the capture of the inventor by the company in which he was employed.[95]

The special character of German patent law also consisted in the detailed preliminary examination, which was intended to prove the seriousness and significance of an invention, and in the required proof of a new idea; for this idea, not a complete machine, was protected by patent law; in this respect, too, German law differed from American law. With this idealistic conception of technology, the law corresponded to Reuleaux's endeavor to deduce the concrete technology from intellectual constructions, while in this respect it did not meet the practical requirements of the patent law.

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This was a rather alienating experience for mechanical engineers and made them dependent on scientific expertise. A great inventor such as Nicolaus August Otto failed before the patent court partly because he was unable to explain the processes in his gas engine in a consistent and conclusive manner.[96] In the Deutsches Museum in Bonn, it is presented as particularly grotesque that the patenting of the lifting of sunken ships by pumping in styrofoam was rejected with reference to the fact that the idea had already appeared before in "Donald Duck"!

According to widespread opinion, German patent law was particularly tailored to the interests of the chemical industry, where there was a particularly close relationship between research results and innovations in production. But the patent success of one company was often a threat to the other; patent disputes became a permanent feature of the chemical business. Caro complained that these controversies were, albeit as
"Necessary evil" unavoidable, "a cancer for the industry";
"the best workers were wasted in protracted and unsatisfactory battles". There were times when company bosses would go to court and bash each other over the head with their insider knowledge in such a way that the fame of chemistry as a "scientific" industry threatened to crumble: Heinrich Caro trumpeted that the dyes for Congo red, which Bayer wanted to patent, could even be produced by his lab assistant without instructions; Duisberg fired back that his lab boy could make the "most beautiful rhodamine" according to BASF's patent. One of the roots of the later merger to form IG Farben lay in such embarrassing scenes.[97]

Originally, patent law - in agreement with chemistry - only protected processes, not products; subsequently, however, methods were developed with which "only by using new materials could a myriad of new substances" (Caro) be produced. A patent on such processes would have created an overwhelming monopoly; in addition, the patenting of countless new substances produced using known processes would have been prevented. In 1888, the Patent Office decided that a process was patentable if and to the extent that it achieved a new and significant "technical effect". This legal concept reflected the fact that the essence of technical development is not just new ideas. Later, even slot machines could be patented. Hoffmann's starch factories in Bad Salzuflen - the largest industrial company in the Lippe region after it was founded in 1850 - enjoyed nationwide success, similar to Oetker's pudding powder factory in neighboring Bielefeld, with a relatively simple product where the packaging was the most important factor; significantly, their main legal battle was not over patents, but over their trademark, the symbol of cleanliness: the cleaning itself.

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white cat, which is why they even got into trouble with the excavator company "Caterpil- lar"![98]

Apart from the patent system, what practical significance did science have for chemistry, which was already regarded in the 19th century as the prototype of an industry based on science? Despite his superlative advertising, science did not play a leading role in industrial chemistry during Liebig's lifetime. Even "the bright day of Kekule's theory" (Caro), the theoretically epochal discovery of the ring structure of benzene (1865), had no immediate technical consequences; the production of the first aniline dyes began independently of the benzene theory. The first chemists were employed at Bayer's paint factory in Elberfeld in the 1960s; however, they were dismissed again "after they did not invent anything new or the like".

As long as industry was guided by the idea of rapidly exploitable inventions rather than long-term development, chemists were in a precarious position. As late as the 1980s, it is reported that they had to spread lard sandwiches for the craftsmen. It was only in the following years that a permanent influence of research on production developed, anchored in the company structure.[99] At that time, the research laboratories of the leading German chemical companies gained a scope that was unique both in comparison to other industrial sectors and from an international perspective. But these research dimensions were more a consequence than a cause of industrial advancement; science served as a means of maintaining a leading position that had already been achieved. Even in the period that followed, the success of German chemistry depended largely on organization and marketing. A scientific basis was not available everywhere in chemical production in the same way as in dye production. Even the process of textile dyeing, the combination of dye and fiber, defied theory. The "scientific penetration of practice branching out into the last veins of production", which Caro believed he had already recognized in 1891, remained an unattained ideal for a long time due to the lack of technical expertise among chemists. For the pharmaceutical industry, the allegedly strictly scientific basis of the drugs had a high advertising value; however, this flaunted scientificity concealed the fact that drugs were still essentially invented by trial and error, without the side effects being foreseen in advance. At the beginning of the 20th century, there were still reports from the production of artificial silk that "for the analysis of fuming sulphuric acid, the masters simply spat into the acid containers. When it fizzled, the acid was more than 90 percent".[100]

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Electrical engineering was regarded as the prototype of a technology born of science. "In no other field of activity does the engineer owe so much to science as here," asserted an article in the journal *Prometheus in* 1894. Nowhere else did the technology of the 19th century transcend the boundaries of perception in such an impressive way. But for a long time, electricity was not only incomprehensible to the senses, but also to theory. People only began to understand this mysterious force when they *worked* with it. Werner von Siemens invented the dynamo-electric machine by trial and error, and for years afterwards he expected little benefit for his company from students. Even in the seventies, it was still the case that a machine at Siemens was designed without calculations;
"Every larger model was developed and tested purely by feel; if the windings became too hot, a stronger wire was used - this was the recipe for all details". The famous Edison, who despised all university studies and formal education throughout his life, proceeded "purely empirically, without any systematic approach". This is how not only the light bulb was created, but also the telephone. "The practical electrical engineer has so far worked almost entirely without theory", was still being said in 1886; and high and alternating current once again gave practice a far head start over theory.[101]

In his old age, Siemens placed great hopes in science to bring precision mechanics ("exact work") to a higher level and used his influence to found the Physikalisch-Technische Reichs- anstalt (PTR); however, industry was disappointed when the PTR developed into a purely physical institute under the direction of Helmholtz. According to Helmholtz himself, he tended to see technology as a kind of
"higher watchmaking". Germany did not gain a scientific lead over England in electrical engineering; the success of the German electrical industry can be explained by other circumstances, not least the alliance between the energy industry and local politics. The scientificization of electrical engineering education in the late 19th century led to a temporary fixation of experts in Germany on "power current", while communications engineering was very unjustly neglected or left to the "so-called practitioners". As a result, wireless telegraphy became - according to the confession of one expert - the "ignominious defeat" of science.[102]

Even in the period of reconstruction after 1945, practitioners liked to quote the verse: "First question: What is theory?/If something should work, but no one knows how./ Second: What is practice? Don't ask such stupid questions! When something works and nobody knows why." Wolfgang König begins and concludes his investigation into the interplay between industry and science in the genesis of the

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German electrical engineering with the words of Friedrich Engels: "If society has a technical need, this helps science more than ten universities." His quintessence: at least until 1914, science had benefited far more from electrical engineering than vice versa.

The importance of science for the *heavy industry* of the time is even more questionable. Here, too, there is the thesis that the "great and decisive improvements" that have been introduced since the transition to coke smelting are "almost exclusively due to expanded scientific insight" (Karl Helfferich). However, this can only be accepted if "scientific insight" is not understood as the result of systematic, professionalized research. The decisive breakthrough in the mass production of steel was achieved by the metallurgical layman Henry Bessemer, who was a professional inventor, but whose success - as it later turned out - was based on the fact that he happened to have used the low-phosphorus pig iron suitable for his process. Bessemer, who considered his lack of metallurgical knowledge to be an advantage, had some misconceptions about the processes in the "Bessemer pear", which were only corrected a century later. The Ruhr industry had to adapt the process to the ore qualities available here with some difficulty; according to an admission from 1878, it "arrived at the German Bessemer process unconsciously and without knowing the goal"; "because the essence of the German Bessemer process has not been known to this day". The "so simple and clear theory of the Bessemer process" was then "shrouded in a body of secondary work that was almost impossible to untangle", so that it "did not seem advisable" to "propose innovations from a purely theoretical point of view". Even in the 1920s, the great age of "rationalization", neither the processes in the blast furnace nor those in the rolling mill had been fully clarified in theoretical terms.[103] Even until around 1980, it was the foreman who determined the tapping of the blast furnace; "scientification" only came afterwards with electronics.

Laboratory research detached from the production process, as in chemistry

The value of innovations only became apparent here when they were tested on a large scale. Alfred Krupp "relied above all on men whose technical qualifications were based on tradition and experience". When he appointed the self-taught Richard Eichhoff as manager of the Puddelwerke in 1854, he is said to have said "he will learn a little technology". It was not until the end of the century, with the development of high-quality nickel steel for armaments, that research became more important at Krupp. Krupp's opponent at the time, Ehrhardt, the inventor of the recoilless gun, confessed that he had "learned most of it by doing".

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always learned in the workshops". In the forge, appearance and experience remained decisive even after 1900. "Great brightness is not important in the forge, because the blacksmith can best judge the temperature of the iron when it is not very bright," according to a 1907 guide for engineers. At that time, heavy industry claimed, also to justify its disinterest in research funding, that it "no longer had any problems that could be solved by scientific means".[104]

Machine tools were a particularly typical and lucrative export of the German ironworking industry at the end of the 19th century. However, according to Georg Schlesinger, the first holder of a chair for machine tools (since 1904), it was precisely these machines that remained largely ignored by German science.

"badly neglected". The machine tool "was not regarded as a fully-fledged machine, but only as a mechanical tool that an experienced master craftsman and perhaps an even better technician was good enough to design and manufacture". This opinion was by no means refuted by the USA, the model for German machine tool construction around 1900; rather, from Schlesinger's point of view, American metalworking machines in particular showed "how much a type of machine can be perfected purely through practical experience". In general, the success of the American engineers, for whom - it was said - the model carpentry shop was more important as a training center than the polytechnic, was at that time apt to unsettle the typical German idea that the scientific basis offered the best guarantee for technical success. On the other hand, the high-speed steels introduced in the USA around 1900, whose optimal use required considerably more powerful machine tools, suited the German tradition of heavy machinery and "the German mechanical engineer's peculiarity of wanting and having to calculate".[105]

There was a particular need for theory in large-scale machine construction, and in large-scale construction in general, because this was where the risk was highest and the possibility of orienting oneself on constantly repeated everyday experience was lowest. The pursuit of a more scientific approach to technology was therefore often combined with a preference for large-scale technology. But it was precisely there that the leap from model to realization was greatest. From the middle of the 19th century, large-scale bridge construction, in particular the construction of railroad bridges, gave a decisive impetus to scientific statics. This began in Germany with the construction of the Göltzschtal Bridge (1845-51) for the railroad connection between Saxony and Bavaria. In the end, however, the oversized stone structure made an archaic impression reminiscent of the Roman Pont du Gard. The river iron construction of the Müngsten Bridge, built in 1897, was a different story, demonstrating the economy and elegance made possible by static calculations and becoming the first of its kind.

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became the image of the American Niagara Bridge. The construction was celebrated as a triumph of theory; the chief engineer, however, plunged into the depths before the inauguration for fear of having made a fatal miscalculation. Calculations were unreliable, especially for large bridges, where wind pressure and material problems were the most important factors. "Strength coefficients of our modern materials, wind pressure issues - everything is so uncertain that one can calculate with tenfold or twentyfold or thirtyfold certainty, depending on the mood, without going very wrong." (Max Eyth)[106]

Comparable problems were encountered in efforts to achieve exact calculations in large-scale mechanical engineering, especially in power plants. Although the need for theoretical calculations was greater than ever before, it was and remained customary to add considerable safety margins to the calculated material thicknesses, depending on feeling and habit. Theory by no means superseded experience, but the correct handling of theoretical results in practice required a great deal of experience. The pursuit of exact scientificity was in a certain tension with the pursuit of technical innovation; because if you wanted to calculate everything exactly for an innovation, you would never get to the end.[107]

Initially, "science" in the sense of experimental research in the laboratory only existed in chemistry. In engineering, it first emerged at the end of the 1970s in connection with materials testing, in the institutionalization of which Germany led the way internationally at the time. However, materials research remained purely empirical for a long time; it was not until the middle of the 20th century that it was possible to derive material properties from the molecular structure of materials. To this day, research into corrosion and wear remains dependent on practical experience; laboratory experiments alone do not provide reliable results. Even a phenomenon as central to technical practice as friction was only accessible to theory and laboratory experiments to a limited extent in the 20th century.[108]

There were certainly a number of innovations that were highly inspired by science and were also recognized abroad as German specialties, such as top products in the optical industry or Linde's cooling machine, which was born out of theory. The triumvirate of Zeiss, Abbe and Schott offered the perfect example of a synthesis of science and technology, as well as traditional craftsmanship and industrial organization. The refrigeration machine made the brewing industry independent of the seasons: particularly important after the end of the "Little Ice Age" in the late 19th century, when it became more difficult to supply the ice cellars with ice. The continuity of production enabled the use of steam engines on a large scale and unleashed *economies of scale*. The quality control of fermentation processes in brewing was the industrially most important origin of modern biotechnology.

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Until then, the success of the fermentation process had been a matter of luck. Modern beer brewing in particular, which has cultivated its pre-industrial traditions with growing fondness, is a technology based relatively heavily on science.

Here too, however, research received significant impetus from technical experience. The history of technology shows time and again that theory benefits from practice at least as much as practice benefits from theory; nuclear physics in particular has at times obscured this insight. As far as the triumph of German beer in particular is concerned, it was based not only on science, but also on the introduction of bottled beer - which was initially opposed by the brewers: the mass production of bottles, the mechanization of bottling and the invention of cheap and easy-to-use bottle caps, which ensured that bottled beer also retained its head - which was discovered to be the particular pride of German beer - in all its glory. Gustav Stresemann, the later statesman of the Weimar Republic, wrote his dissertation on the rise of the Berlin bottled beer trade around 1900 and vividly described how beer had only become an everyday staple for Berlin factory and construction workers thanks to bottling.[109]

Rudolf Diesel, the prototype of the inventor obsessed with a "principle", began as a student of Linde's and "refrigeration machine man", who, trusting in the right theory and with the ideal of the "perfect" engine and theoretically optimal efficiency in mind, overcame agonizing dry spells and devastating failures, and was even able to keep large companies in line. However, the long development history of the diesel engine also shows in exemplary fashion how an invention that can only be developed to market maturity by large-scale industry is at the same time changed to such an extent during this lengthy process determined by industrial interests that virtually nothing remains of the original idea. The diesel engine, which its inventor wanted to be characterized by maximum efficiency, the use of inferior fuels and usability in small businesses, became a typical drive for large machines for a long time, whose economy improved with increasing capacity, and was characterized above all by a certain fuel quality.[110]

The development of the Mannesmann cross-rolling process at the end of the 19th century was a comparable process: it fascinated the technical public because it was theoretically impressive; this made it possible to overlook the enormous difficulties in practice, which brought the Mannesmann company to the brink of ruin. The enthusiastic support of the Mannesmann brothers by Reuleaux, who was even able to convince Werner von Siemens of the ingenuity of this rolling method, had a signal effect. *Prome-*

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theus found it "striking" that "the vast majority of theorists were in favor of the skew rolling process, while the men of practice were, if not opposed to it, at least hesitant".[111]

Since it was widely believed - rightly or wrongly - that science was particularly needed in technology when maximum efficiency was required, interest in scientific methods increased with the price of coal and engineers had an interest in criticizing waste and pointing out the enormous potential for savings.[112] Here, the quest for the "scientification" of technology had a constructive character. At the end of the 19th century, however, there was also a convergence between scientificization and the arms race, which can be seen particularly clearly at the Krupp company: the race between cannon and armour for the navy led to the systematic development of ever harder types of steel.

In contrast, science played little or no role in other new techniques in the second half of the 19th century. Photography, for example, was a classic playground for amateurs. The automobile also remained the domain of practitioners until well into the 20th century; in terms of the history of technology, it was a conglomerate that ran counter to the academic structure of technology. As a rule, scientificization meant specialization, but this contrasted with the growing complexity of some areas of technology. For example, it was ill-equipped to meet the demands of urban engineering, sewerage and the installation of new transportation systems. The city of Frankfurt am Main commissioned William Lindley to manage the sewerage project (1867-78) and placed him in charge of the civil engineering department in 1883, although local engineers protested because Lindley "contrary to German custom, had never attended a technical college". The growing drainage systems of the expanding cities had to be adapted to the specific local conditions; they could not be deduced from any general theory. James Hobrecht, under whose direction the Berlin sewer system was built in the 1870s, which became a model for other metropolises around the world, had to deal with the fact that the construction sites dug everywhere were constantly changing the hydrological conditions of the drainage network.[113]

Even a leading representative of the technical university system such as the pugnacious Riedler, who waged a multi-front battle against both an excess of theory and excessive specialization and against the "proletarianization of the engineering profession", repeatedly remarked that the importance of knowledge and science for technology was vastly overestimated in Germany. Moreover, since the 1870s, there had been widespread dissatisfaction in industrial circles with the academization of technical training.

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This was probably not least due to the resulting salary and status expectations.[114] In all of this, it is clear that the decisive driving force behind the scientification of engineering education was not the requirements of technology, but the professional interests of the engineering elite, supported by the prevailing educational ideology in Germany. "When something becomes important in Germany, it becomes academicized, so to speak, and is given an official basis," remarked an English observer.

However, when the oldest generation of technical education turned partly into universities and partly into general education "Oberrealschulen" (1878), a "skills gap" (Wolfgang König) emerged in the area of intermediate technical education. Around 1900, a new intermediate level of technical colleges took shape, which was able to meet the requirements of industry in some ways more directly and flexibly. In the late 19th century, the VDI found itself torn between the interests of the academic profession and the wishes of industry. However, despite fierce opposition, it remained open to non-academics and helped to establish the new universities of applied sciences. This educational sector - a German specialty in its own right - became no less important for technical practice than academic education; the importance of universities of applied sciences is currently still growing.[115]

The connection between the history of technical colleges and the history of technology is still strangely under-researched: partly perhaps because it was taken for granted per se, but partly probably also because for long stretches it does not exist at all. At some points in the history of technical education, the demands of practice seem to have come through: for example, in Riedler's fight for the introduction of the laboratory into mechanical engineering teaching and his "seven-year war" against Reuleaux and his theoretical approach. However, "practical relevance" could also be used to conceal a lack of intellectual coherence and neglect of teaching in favor of lucrative contract work. Georg Sie- mens, who had studied under Riedler, later complained: "His lecture consisted of him throwing a number of more or less incoherent chunks at us."

Around 1900, the science of mechanical engineering in its practical application, the construction of machines, was not much more than a reproduction of what practitioners were doing anyway.[116] In chemistry, where the laboratory had been at the center of education since Liebig, industrial interest in practical research at university institutes waned around 1900; industry now had its own laboratories. It was now possible for roles to be distributed in such a way that an industrialist like Duisberg advocated the priority of

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The university chemists fought fiercely and not without success for the priority of the research work of doctoral students in the laboratory - which was also very lucrative for them. Fritz Haber, famous in the chemical industry as the father of ammonia synthesis, devoted most of his efforts to extracting gold from the sea. The relationship between science and technology is not only characterized by growing affinity, but also by the emergence of new areas of tension - above all the tension between basic and applied research - which in part resulted precisely from the successful cooperation between science and industrial technology.[117]

5. Industrialization and professionalization of the inventor - the development concept in technology

The more intensively the scientificization of technology was pursued, the more it became clear that not everything could be calculated in advance for new technologies, but that they could only be brought to success through longer processes of experience. Therefore, the steep career of the concept of technical *development* took place in parallel with the efforts to scientify technology. The English language distinguishes between intransitive *evolution* and transitive-active *development*; the German term
"Development" means both. The technical "development" contained an organic metaphor: it fitted in with German traditions of thought. And the transfer of the principle of evolution to technology made sense: successful technical innovations generally did not take place in abrupt leaps, but in many small steps, and the learning process that took place over many years of practical experience could only be shortened and accelerated to a limited extent. There was a concept of technical "development" that had retained its organizational meaning, as when Otto Lilienthal explained that it was not possible to come closer to flying through any invention or great leap, but only "through constantly increasing experience of free, stable and safe movements in the air": "Yes - 'development' is the right term, 'development' the right term, the heeding of which must make its way into flight technology." "Development" originally contained a sense of the benefits of a certain leisureliness. *Prometheus* noted in 1903 that German high-speed steamship construction had been preceded by "long years of development".[118]

Overall, however, the development concept in technology took a turn that corresponded to the academization of engineers and also the growing involvement of industry in inventions: innovation was seen as a

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The process of innovation was a planned and methodical one, pursued to industrial maturity, from which chance was banished as far as possible, even if it was still cultivated in anecdotes. In the chain of innovations, one should emerge organically from the other and point the way to further discoveries. "Research and development", often abbreviated to "R&D", became the accepted term worldwide, and with it the deceptive illusion of technical progress that could be programmed without regard for the market or nature. The once intransitive concept of "development" became more and more transitive: Teams of engineers develop the technology - not the technology itself develops over time through the wealth of experience.

Behind the concept of technical development was the desire of engineers for a secure long-term existence, based not only on lucky intuition but also on professional competence, and the interest of industry in organizing innovation under its own control. In the late 19th century, the reference to the great expense of technical innovations served to justify large-scale industry and to justify the possibility, opened up by the German Patent Act, of transferring patents to companies. One could ask whether the institute of the patent with its protection of the "idea" was not also historically outdated with the individual inventor and the invention that could be defined as an individual act. Riedler wrote somewhat exaggeratedly in 1916:

"There are no longer any absolute innovations, no absolute inventions; they would have to be absolute new discoveries, but these are rare. In the 1980s, 'invention' was replaced by the broader concept of new design, structural and operational improvements; everything is already known, everyone has predecessors, and comprehensive patent value can no longer be achieved. "[119]

There were different ideas about the carriers of technical progress, depending on whether one saw the continuity of technical development as being based more on basic research or more on the small-scale experimental work of large industrial laboratories. When Reuleaux is said to have "introduced the idea of development into technology", this refers to the goal of inventing according to plan based on a systematic theoretical approach.[120] The chemical industry, on the other hand, was characterized by "serial inventions" made possible by the mass of human and financial resources, which were based on testing certain processes with ever new substances. This was a trump card of the new large-scale industry.

While intuitive, individual and versatile invention was considered a natural talent of the English and Americans in the 19th century, systematic, large-scale organized invention became the speciality of German industries until the 1920s and 1930s,

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especially in chemistry. Later, when the Manhattan Project made "research and development" on a gigantic scale the basis of the USA's claim to technical leadership, the organization, staying power and disciplined cooperation of large research groups had until then been regarded as a particular strength of German technology. An English observer, Shadwell, wrote in 1906:

"The Germans are slow, purposeful, careful, methodical and thorough in their work [...] They are not an enterprising and adventurous people [...] they need time to think and act; they need their regularity, their familiar surroundings, their predetermined path. But they have an unrivaled ability to find the right path and to follow it unswervingly. "[121]

Two or three generations earlier, during the Biedermeier period, progress enthusiasts saw German leisureliness as a hindrance to the advancement of technology; by 1900, however, even the inertia of the German collective mentality had become a driving force behind technical progress.

One must be wary of national stereotypes: there were other judgments at the same time. Shadwell's impression only applies to certain industries, and a generation later the image of Germans had changed. In the middle of the 19th century, science and technology still presented a different picture in Germany. Alban complained in 1849 that in Germany, unlike in England, "everyone just wants to get to the bottom of a company, they just want to earn money". When Loewe estimated that the conversion of his company to American series production in 1870/71 - including the construction of the relevant machines - would take around ten months, he was already talking about "endless difficulties" that required the utmost perseverance and consistency.[122]

Even in the late 19th century, large-scale technical development with a long-term perspective was still rare outside of chemistry. The closest thing to a role model was Siemens, which in its early days (1851/52) had experienced a bad fiasco with the hasty laying of poorly insulated telegraph cables and since then had made a thoughtful, methodical approach to technology the hallmark of its corporate style. Werner von Siemens preferred to see his company as a technical development institute. But even he did not have an extensive research apparatus separate from production like Bayer; and his rival Emil Rathenau preferred to buy innovations from outside rather than develop them himself.[123]

Industry- and discipline-oriented specialization in certain areas of innovation only gradually became the norm. The Siemens brothers were still active as all-round inventors, and for a while they were successful: especially in the field of gas technology, the future major competitor of electricity. After the very first electrical euphoria in the 1850s

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Around 1870, the sobering opinion was that the innovation potential of electricity had essentially been exhausted![124] But it was precisely during the subsequent depression, when the prevailing tendency was to prevent price competition wherever possible and to seek profits in market dominance, quality and new products, that technical development became a consistently pursued strategy.

From the fact that the links between science and industry were becoming ever closer, it was often concluded that the new era was characterized by the "lightning-fast" implementation of scientists' ideas in practice. To this day, it is often assumed that there is a law of the increasing shortening of the period between invention and application in the modern age.[125] However, indigo synthesis, the artificial production of the "king of dyes", became a milestone in the development of time benchmarks for the duration of innovation, which nurtured the confidence in Germany that the means of chemistry could be used to gradually devalue the English Empire: Here, it took almost 20 years from Bayer's success in the laboratory to profitable industrial application, and the development to market maturity became a lengthy industrial experience process of its own kind that transcended the boundaries of science. Such a long development period was not typical; later, two years was considered a normal period for the development of a new dye. But the synthetic production of quinine, a magical goal similar to indigo synthesis, was only achieved half a century after the first attempts. In the pharmaceutical sector, whose importance for chemistry in the
20th century, a hasty marketing of new products could not be avoided.
products could be dangerous; only years of experience proved their usefulness.[126] In economics at the time, it was above all the psychologically sensitive Vienna marginal utility school that emphasized the time factor in the development of a new product until it was ready for the market. Carl Bosch later formulated the rule:

"A major technical problem takes 10 years to become ready for production, it is useful for another 10 years, and in the next 10 years it is already falling apart. By then another problem must have been solved. What we earn from a successful invention must be invested in the preparation of a new product. "[127]

This was already the case in the era of high-pressure chemistry, when the enormous effort and wealth of experience in ammonia synthesis was urging to be used for cau- chuk and fuel synthesis as well, and in the end it turned out that the concept of technical development, pushed to the extreme, was worryingly far removed from the market.

Here, as with the later large-scale nuclear technology projects, it becomes clear that the long-term technical development contained an ideology: a concept of technical progress per se. If the replacement of natural by

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synthetic substances was "progressive" in principle, then and only then

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there was the certainty that even the synthesis, which was pursued with enormous effort, would ultimately lead to success. The concept of technical development only developed its full ideological dynamic in the second half of the 20th century, when "development" had become Americanism and the job of "development engineer" existed.

From the perspective of large-scale industrial development, the old-style inventor operating as a dilettante and on his own initiative became a semi-ridiculous figure.[128] The way in which certain directions in industrial technology were also consolidated by corresponding infrastructures discouraged the non-professional inventive spirit seeking unconventional solutions. This meant that a source of amateurish pleasure and personal initiative in relation to technology was lost. And yet the professionalization and industrialization of invention only succeeded to a limited extent. Reuleaux's goal of laying the theoretical foundation for systematic and systematic, teachable and learnable invention was not achieved. Instead, people complained about
"poverty of inventors" at the technical universities and noticed a decline in innovativeness in leading German industries, especially in the period after the turn of the century, when the institutionalization of inventing should have borne fruit. The overall character of the following period was characterized not so much by basic innovations, but rather by larger dimensions, networking and rationalization. In this way, innovations were channeled in certain directions and new alternatives were sometimes inhibited to an unthinkable extent. However, not only at the end of the 19th century, but also in the era of the transistor and microelectronics, there were repeated opportunities to marvel at "how small inventors put huge research laboratories with thousands of scientists in the shade".[129]

6. Model USA and "American danger"

An initial phase of intense confrontation with American technology lasted from around 1870 until the decade after the turn of the century. This created a field of tension that has strongly influenced the dynamics of technological development in Germany to this day: since 1870, a large part of German technological history can be described as a sequence of Americanization spurts, but also of justification of German trends with American models, adaptation of American technology to German conditions and counter-reactions to "Americanization". As we have seen, American influences began in the early 19th century, but it was only from the 1870s onwards that American technology was perceived as a model.

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This led to a tendency to regard technical system perfection as "American" per se, which was more of an ideal than a widespread reality in the USA. The "American" became a sign of quality or, depending on the attitude, a nuisance of technical superlatives.

In this first phase, particular attention was paid to the machine industry. The victory of the northern states in the American Civil War was not least a victory of superior production technology. Series production with interchangeable individual parts, which in the early 19th century was still a manufacturing method that could only be mastered with expensive skilled workers, was increasingly mechanized: first on a large scale in weapons production, and subsequently also in the civilian economy. This production method was most sensational in the 1870s in the Singer sewing machine factories, although, to be more precise, skilled manual labour was by no means completely eliminated there, but rather a combination of "European" and "American" production methods was practised.[130]

As early as 1855, Clemens Müller, who had become acquainted with American manufacturing in New York, founded the first German sewing machine factory in Dresden; a decade later, it was considered the largest in Europe. The best-known German pioneer of what was subsequently regarded as the "American" production system was Ludwig Loewe, who, originally a merchant and, like other pioneers of "American" methods (Rathenau, Schlesinger, Münsterberg), of Jewish origin, turned his attention to sewing machine production. In 1870, a trip to America in the "land of unlimited possibilities" gave him confirmation of the "idea on which our company was based from the outset and which had not yet been implemented anywhere in Europe". Somewhat exaggerating, he described the entire American machine industry as vastly superior to the German one, which produced with machines that "from a scientific point of view were not really capable of working at all" and only functioned poorly because "the German worker was a capable material". According to Loewe, all American factories, in which everything looked "enormous", "magnificent" and "most magnificent" in his description, were organized through and through according to a uniform system, from whose

"Necessity and advantageousness in Germany until then
had not yet had a clue". "System" - a term that was suspicious to empiricists - was the new magic word for him, and he summed up the alleged contrast between the production style of the New World and the Old World in the formula "systematic - empirical". Yet, as he noted in passing, the American production style he praised was not cheap at the time, but demanded "disproportionately high prices". Loewe proclaimed the goal of outdoing the Americans with his own methods

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and his sewing machine factory became the "best equipped in the world" and the
"largest on the European continent" - it was the superlative style that was considered typically American in Germany at the time, but which also became typically German in the Wilhelmine era.[131]

However, the engineer Petzold, who helped Loewe to procure American machine tools, warned as early as 1871 that "the greatest caution is necessary" when taking such a step, as "the slightest mistake" could "have the most disastrous consequences". The "American labor system" could "easily become a dangerous toy" in the hands of its new German "adepts". All too soon, during the boom of the founding years, it became clear that there was no market for mass production of American-style sewing machines in Germany. Despite the high-sounding fanfares, Loewe reacted promptly to the situation, switching from mass production to quality production for "safe customers" and concentrating primarily on the manufacture of weapons: this was the only way to realize profitable mass production in the German machine industry of the time. But even there, Loewe *made* "wise limitation" and the renunciation of unlimited testing of *economies of scale* his basic rule; he, who had initially been the most uninhibitedly enthusiastic about American methods, recognized with particular clarity the need to adapt them to German conditions. The Loewe company, which also turned its attention to toolmaking, also became a pioneer of American methods in this sector in the 1990s, to such an extent that even the Americans themselves recognized it at the time: "The best American tool store is now in Germany." The "Loewe standards" established at that time formed the basis of the national standards system created during the First World War. However, the Loewe company, shrewd by experience, held back from consistently introducing the flow system even in the 1920s and contented itself with a combination of workshop and flow system that corresponded to flexible small series production.[132] It is a company history that demonstrates the path from unrestrained enthusiasm for America to the adaptation of American production methods, like a didactic play.

Werner Siemens, who knew Loewe well, had also founded a company after 1870.

Phase of American euphoria. With an emphasis and radicalism that is conspicuous in the otherwise rather reserved man, he seemed to want to reorganize his entire company according to the idealized American model. He wrote in 1872 that the company had been "eagerly endeavoring to do everything with special machines like the Americans" for "a year in particular"; this had "already proven itself brilliantly".

"Now we are all convinced that our future salvation lies in the application of the American method of work, and that in this sense we have to put all of our efforts into

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management must change. Only mass production must be our task in the future, in this we can satisfy every need and overcome all competition! [...] Arbitrary changes to our fixed designs must become just as ridiculous as if someone wanted to order a modified sewing machine."

At that time, the "American room" was set up at Siemens for the series production of certain torpedo and telegraph devices. It was managed by a former worker who had been sent to the Loewe sewing machine factory for a few months to study; the foremen, on the other hand, were "quietly antipathetic" to the new methods. But the "Ameri- canersaal" remained an island in the company as a whole; the foremen continued to rule the roost around it, even if the engineers complained about the self-will of the workers.

"Gentlemen artists" annoyed. In the following years, Siemens reacted allergically to American innovations, especially to the press and advertising hype surrounding Edison. By the 1990s, the company had become - from a later perspective - an "outdated and sleepy" business: a situation in which the junior, Wilhelm von Siemens, had his own American initiation experience.[133]

AEG, which at the time threatened to overtake Siemens, began life as the German Edison Company and distinguished itself from the outset by importing American technology and American production methods. In keeping with the new standardization pathos, Emil Rathenau branded it the "cancer damage" to German industry that every machine master has its own rules: Getting rid of this bad habit was a question of to be or not to be. At first, Loewe was his role model; he brought an American screw-cutting machine from the World's Fair in Philadelphia to Germany, but failed "miserably" with it, because screws were cheaper to make by hand in Germany at the time. Edison's inventions could not be transferred in pure form to industrial production: Rathenau also experienced the need to modify American technology for his own conditions. In the upcoming heavy current business, series production was only applicable to a limited extent anyway; in the construction of power plants in particular, much depended on national and regional conditions.[134]

Before 1914, American models were of less importance in German chemistry than in mechanical and electrical engineering. But a trip to America in 1896 also gave Duisberg confirmation of his plan to build the new Bayer plant in Leverkusen from the production process upwards, replacing manpower with machine power wherever possible and making the entire plant as autonomous a unit as possible. He was particularly impressed when he did not see a single person operating the plant in the furnace house of an American sulphuric acid factory.

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It was a highly unusual sight for a German at the turn of the century. On another trip to the USA in 1903, however, he reacted more dismissively to the American impressions. When he explained to the New York Chemist Club that the global position of the German chemical industry was based on the "scientific spirit, which seems to be a characteristic of the German national character", and at the same time assured the Americans that they too would have to learn in future "that the only way to reach the goal is to unite science with technology", he was proclaiming nothing but truisms from the perspective of the German chemist of the Wilhelmine era; American experts, however, regarded the lecture as an embarrassing affront. Duisberg had his own reasons when he publicly warned in 1926: "We like to pose as the teachers of foreign countries. It would be better if we ourselves wanted to learn a little more from abroad. "[135] It was the time of the founding of IG Farben, when the need for industrial concentration was usually justified with reference to foreign chemical giants, and it was an era when "Americanization" was propagated more unreservedly in German industrial circles than in the German Empire.

Here, and even earlier, the confrontation with the American technology within a larger framework that extends into cultural conflicts and political symbolism. "America" was the epitome of progress unhampered by tradition, but since List it was also the model of a combination of progress and protective tariffs and thus a symbol of domestic political significance in the situation of the 1870s. The way in which "America" functioned as an irritant was also a reflection of variants of German nationalism, where fascination with the USA predominated in some cases, while in others it was outweighed by educated bourgeois or ethnic aversion.

There was no talk of an "American danger" in industrial circles in the 1870s. Nor would there have been any reason to do so: American industrial products were generally too expensive on the German market at the time. Only German farmers were already feeling the effects of competition from American grain. Where American methods were used in industry at that time, it was not due to competitive pressure, but rather "for reasons of principle" (Landes), because this was the direction they were heading in anyway. At the time of the World's Fair in Philadelphia (1876), Reuleaux and his fellow campaigners referred to the American example in order to demonstrate the blessings of the patent system and the superiority of quality over price competition; Reuleaux emphatically opposed the "idea cultivated in Germany that the Americans were only capable of producing cheap mass-produced goods". Not only the American machine tools, but also the American

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Tools were highly praised; "America" was by no means only synonymous with the replacement of manual labor by machines. The diligence of American workers was also regarded as the American secret of success.[136]

For several years after the turn of the century, the *"American danger"* became a buzzword in German journalism. The German-American industrial psychologist Hugo Münsterberg explained the exaggerated alarmism by the fact that the Germans had not really perceived the USA as an industrial power for too long. Drawing on the American anti-trust polemic, people were now terrified of American gigantomania; the view of the enormous resources of the USA reflected German imperialist ambitions and the basic sentiment that Germany could only survive as a world power in an age of world powers. The leitmotif "rise or fall" permeated the technical literature: a country - so it was said - that allowed itself to be continually overtaken by the USA in the "productivity of its labor" would "gradually sink into a kind of Chineseness". "Any suppression of technical progress" was therefore dangerous in the current Germany, as technology had "an enormous expansive power within itself". Exaggerated ideas about American technology were spread. The German machine tool industry in particular, which had been particularly hard hit by American competition before 1900, achieved an increase in exports from 9,000 to 58,000 tons between 1901 and 1907![137] It corresponded particularly well to the German dream that shines through in some technical journalism as well as in the Old Shatterhand myth: to surpass the Americans in their own field. But the growing export share also made it more susceptible to the psychosis of the international race.

Within the German mechanical engineering industry, a completely new
The situation differed from that of the American competition in products such as sewing machines, bicycles and cash registers, where mass production methods could be consistently applied, and in the production of power tools and machine tools, where diversification according to specific customer requirements brought decisive advantages. Both branches of mechanical engineering diverged in terms of technology, type of worker and sales strategies, although the former, with its growing demand for machine tools, influenced the latter. Sewing machine and bicycle factories were highly specialized in certain products and faced international competition; steam and machine tool factories usually had a broader product range and were generally geared towards a regional market in the 19th century. The first branch of industry felt compelled to adopt the methods of American mass production as far as possible, while the second was able to go its own way to a greater extent.[138]

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The mass production of sewing machines represents a milestone in the history of technology as well as in the history of women's work, where it gave a foretaste of the fact that technical progress can also produce new domestic work with new opportunities for exploitation. It was the first machine that could be sold to private households like a consumer good; it contained a relatively sophisticated mechanism that took a long time to develop and - more than the spinning and weaving machine - required a rethink of the motion sequence of manual labor. Here, more than in the textile industry, the transition to mass production contained an impetus for system planning, for linking individual processes. Before 1914, Germany seems to have been the only European country that was able to compete with the USA in sewing machine production. However, under the conditions of the narrower, seasonal German market, it often proved advantageous not to specialize the production facilities entirely in the manufacture of sewing machines, but rather to interpose other productions according to the seasons, such as the manufacture of bicycles at the end of the 19th century, the ideal complement in terms of seasonal fluctuations in demand. The sale of bicycles flourished in the summer and sewing machines at Christmas. The disadvantage of this combination was that both products were highly dependent on the economy and exposed to international competition. For this reason, and for technical reasons, the combination of bicycle and gun manufacturing was sometimes preferred.[139]

Technically related to the sewing machine was the mechani-
The USA was also the starting point for the modernization of shoe production. Here, the first incursion of American mass production took place as early as the 1860s - precisely at the time when Wagner's "Meistersinger" glorified the guild culture of the shoemakers and at the same time celebrated the combination of tradition and innovation - and triggered some fierce journalistic reactions. Sewing and shoe machines hit the tailors and cobblers, the two trades with the highest traditional numbers, albeit long since proletarianized. The level of mechanization at that time did not necessarily lead to factory operation. The early sewing machines were hand-operated, the early shoe machines were foot-operated. Skilled manual labour had not yet been eliminated in shoe production, especially as the German shoe industry was much less specialized than the American one. From the 1990s onwards, chrome tanning, which came from the USA, pushed back vegetable tanning agents and, at the same time, manual tanning.[140]

If one follows a spokesman for typification and "Americanization" such as Georg Schlesinger, the "rebirth of the German machine tool" occurred around the turn of the century - when the term "machine tool"

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The German mechanical engineering industry had the advantage over its English competitors in that it did not take too much pride in tradition and was therefore more adaptable. German mechanical engineering had the advantage over its English competitors in that it did not cultivate too much pride in tradition and was therefore more adaptable. There was a relatively high degree of opportunity for independent German developments in drive and machine tools. The contrast between a German and an American path became popular early on: In Germany, where the limit of economic efficiency was generally at higher capacities than in the USA due to coal prices, heavier types predominated - as was the case with machine tools. Here, greater value was placed on durability and economical fuel consumption. In this context, people liked to emphasize the "scientific" basis of their own machine production, although this was only true to a limited extent in the 19th century. In the USA, on the other hand, there were a large number of smaller and lighter steam engines that could be mass-produced; simple construction and convenient operation were more important than minimal fuel consumption.[141]

The German pioneers of the American system criticized the diversity of types in German mechanical engineering and the willingness of manufacturers, following the example of Berlin's Wöhlert, to fulfill all special customer requests with
"Mach ick" to answer. However, this criticism was not rooted in a purely economic calculation, but also in a certain image of progress in manufacturing technology; because at that time it was at least as evident as it is today that the success of the German machine industry was essentially based on flexibility with regard to individual customer requirements. Even in a company that was "Americanized" after 1905, such as Gildemeister (Bielefeld), the
"Series" of no more than five machine tools of one type. The secret of German mechanical engineering's success had typical traits: As Werner Sombart emphasized, it was "first and foremost our adaptability that enabled us to conquer our position on the world market". And this in turn was the merit of a certain "humility and modesty": a relic of a time when the Germans did not yet have their own nation state.[142]

Agricultural machinery was an early symbol of the "American system". However, some of them required too much horsepower by German standards and contradicted economical and intensive soil cultivation. The USA was also ahead of other countries when it came to woodworking machines; however, because these produced a lot of waste and corresponded to a country with seemingly endless forests, the German timber industry was reserved about "Americanization". As the precision of the machines increased, however, the incentive to mechanize in the German wood industry improved; the World's

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Fair in Philadelphia inspired the founding of Kirchner's "German-American Machinery Association".

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nenfabrik" in Leipzig (1878). German in-house developments also had an early chance in woodworking technology, as the successes of Zimmermann (Chemnitz) and Cramer-Klett (Nuremberg) show.[143] There was even a "Technology transfer" from Germany to the USA. For example, the Solingen blade industry developed automatic grinding machines around 1900, which "revolutionized" the American cutlery industry shortly afterwards, but were rarely used in Solingen itself until the First World War, as quality goods production there was based on the tradition-conscious skilled workforce and their manual experience.[144]

In heavy industry, a typical American innovation of the late 19th century was the improvement of transport routes - as in the "American plan" at Hoesch - and the mechanization of blast furnace coating plants. These innovations in particular were the subject of much discussion in German professional circles and were sometimes viewed with scepticism, as they involved complex, repair- and failure-prone systems that prompted a leading German ironworker to write: "All that glitters is not gold, however, and some intricate designs were only created to counter the overconfidence of the [American, J. R.] workers' associations (Unions). "[145]

The American ring spindle, invented in 1828 - the most radical change in the spinning process since the early industrial spinning machines - only began to gain acceptance in Germany at the end of the 19th century, and in some cases it did not even displace the self-actor until the 1950s. From a European perspective, it was a typically American innovation, with the advantage of higher production output and simple operation, but with the disadvantage of higher plant and energy costs and - initially - poorer product quality. But even in the USA, the number of mules, i.e. older type spinning machines, was still on the rise until 1900. For a long time, ring spinning machines were only suitable for certain types of yarn; it was not until around 1930 that they became as universally applicable as the self-actor.[146]

Lesser-known success stories based on the adoption of American methods of mass production occurred in the German watch and piano industries. In the late 19th century, Germany became the largest piano exporter in the world. The Black Forest clock industry, which had always been able to keep up with the USA in the mass production of wooden clocks, responded to the challenge posed by the "American movements" made of rolled brass from 1870 onwards. Some Black Forest manufacturers adopted American components relatively quickly and successfully and combined them with their own developments. By 1900, Junghans had become the world's largest watch manufacturer. In the following years, it achieved a technical lead in the highly competitive watch market to a dangerous

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This already sheds light on the dangers of the technology race in the 20th century.

All in all, the confrontation with the "American danger" in industry and technology, both then and later, appears to be a sideshow to a broader political and cultural confrontation with "Americanism". An ecological one at that: The "forest slaughter" practiced in the USA, the extreme overexploitation of natural resources, also came into the sights of German criticism of America around 1900. All that was needed was to adopt an American self-criticism of the time. For "Americanism" had its own inner dialectic; and German critics rarely understood this. The American style not only included unrestrained overexploitation, but also fierce public counter-campaigns: in the name of "conservation" and "preservation" of natural resources, "safety" and "efficiency" in technology. In the end, the Germans had to relearn some of the virtues they were once proud of from the Americans.

7. At the limits of mechanization

Epochs in the history of technology are not only characterized by the latest and most sophisticated technology, but also by the limits of the respective technological change and by what takes place at these limits. Society as a whole takes on a different character depending on whether a sharp boundary separates a modern from a traditional sector or whether the boundaries between old and new are fluid and there are wide zones of transition. In comparison to many other countries in the world, Germany is characterized by a fluid boundary. The juxtaposition of highly mechanized and manual working environments does not necessarily have to be seen as a "simultaneity of the non-simultaneous", nor does a traditional sector necessarily have to be seen as backward: Technical innovations are by no means always and everywhere rational; very often, on the other hand, German industrialization relied on the existing broad pool of skilled craftsmanship and, on top of that, created a need for new manual skills and new kinds of experiential knowledge. Germany's craft traditions were wrongly seen as an obstacle to industrialization in general, just as it was a misinterpretation to see these traditions only as a stumbling block for the German labour movement. It would also be wrong to regard the more conventional economic sectors characterized by manual work as marginal under the suggestion of the latest technology of the time; because until the end of the

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19. At the end of the 19th century, production was still predominantly artisanal in character.

In the shadow of the expanding factories, there was an expansion of home-based work. Where spinners and weavers lost their livelihood due to the machines, they typically switched to cigar making: until the hygienists put an end to this domestic cigar wrapping, in which spuke was sometimes used as glue. Advocates of industrial progress and trade unions agreed that working at home was a scandal. If you take a closer look, you will see that there are some exceptions to this blanket judgment. For example, the German Christmas, one of the most successful German export products since the 19th century - albeit uninteresting for technology historians fixated on "basic innovations" - generated an increasing demand for tree decorations and other glittering trinkets that brought in money and were largely produced by homeworkers.

Agriculture, food production and the construction industry - sectors of the utmost economic importance that defined the framework of industrial development - were only affected by mechanization to a limited extent for a long time. However, it was precisely there that traditional manual labor and mass production were able to lie close together. Brickworks, cement and sugar factories, steam sawmills and steam mills, mass production of plows, scythes and hand tools were very compatible with the predominantly manual character of agricultural work, construction and woodworking.

Even before mass production became established for machines, it was practiced in the manufacture of tools. The tremendous growth in iron and steel production not only benefited mechanization, but also the tooling of manual labour to a great extent. In Phila- delphia, the American axes and saws impressed visitors just as much as the American machines. The prevailing belief in the 19th century that craftsmanship was in inexorable decline was refuted by the surprising resilience of craftsmanship in the 20th century and by the statistical facts, even if the relative decline in the importance of craftsmanship within the overall economy is unmistakable.[148]

The theory of decline arose from a romantic idea of the old guild craft, which only corresponded with reality to a limited extent, and a vision of the future in which progress was identical with greater mechanization. If we take independence, the unity of house and production site, the absence of machines and the mentality of the pre-capitalist "food economy" as criteria for craftsmanship, then there was indeed a decline. The situation is different if one defines craftsmanship in terms of labor technology and anthropology.

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The craft is defined as a working world in which manual skills, experience and a feel for materials are crucial, where planning and execution are not, or not predominantly, separate and work conveys self-confidence. Craftsmanship, understood in this way, can also exist in factories.
"Craftsmen-workers" and industrial foremen are to be understood not only as hermaphroditic transitional phenomena, but also as archetypes of industrialization.[149]

The same applies to the large number of small industrial businesses that emerged from the craft sector. Schmoller already saw a "new type of craft business" here, which "does not require both large capital and personal qualities": "Especially where greater personal skill and craftsmanship is required, the small businesses flourish alongside the larger ones." The world exhibitions - starting with London in 1851 - not only gave impetus to mechanical technology, but also, and sometimes even more so, to arts and crafts.[150] Reuleaux's "cheap-and-bad" verdict was not least concerned with the elevation of German arts and crafts.
"a kind of profile neurosis of German arts and crafts" and was still quoted at the founding of the Werkbund (1907).[151]

If the skilled trades in Germany - unlike in England and France - developed considerable political assertiveness, which achieved its first successes with the craftsmen's amendments of 1897 and 1908 - the so-called "small certificate of competence" - and its greatest triumph with the large certificate of competence of 1953, there is no need to
"archaic" phenomenon or the desperate struggle of a declining class.[152] The politics of artisan interests was not a foreign body in industrial development, because this was determined not only by the market and mechanization, but also by organized group power and material-related experiential knowledge.

The steam engine did not eliminate manual labor everywhere. The classic example is the Solingen grinders, who also brought their manual skills and experience to bear in the steam grinding shop. If Solingen overcame the stigma of "cheap and bad" in the 1970s in a particularly impressive way and outperformed Sheffield - in England an impetus for the (supposed) stigmatization of German goods with the "Made in Germany" label - this was not only due to the mechanization of the forging process, but also to the reshaping of the grinders as qualified skilled workers, contrary to conventional opinion. The success of Solingen cutlery was based not least on its "Babylonian diversity". The Solingen blacksmiths fared differently from the grinders, who lost their shaping activity through the introduction of dies (steel molds).

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Figure 16: The Henckels brothers from Solingen display their trademark, recognizable at the bottom of the man-sized knife, as a living image at the 1893 World's Fair in Chicago. The twin sign had already been patented in 1731, making it one of the oldest German company emblems. The Henckels company successfully presented its knives at international exhibitions time and again as products of top quality and helped to establish the reputation of "Made in Germany".

lost. However, years of work experience were also useful in the drop forge, and the manufacture of dies gave rise to a new skilled trade - as demonstrated by the Hendrichs drop forge, which is now an industrial museum.

The Solingen grinders were not unique in their time as "artisan workers"; the neighboring wire drawers in the Mark Brandenburg also retained their artisanal working methods and craftsmanship well into the 20th century; large-scale operations had no technical advantage over the wire mills operated by the streams of the Sauerland. The technology and working methods of traditional Bergisch ribbon weaving, which had already achieved partial mechanization in pre-industrial times but continued to produce in small batches, also survived the introduction of the steam engine: many Bergisch ribbon weavers, like the Solingen grinders, rented a machine connected to the steam engine.

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Figure 17: Knife grinder at the "wet stone", probably in the Henckels company around 1930. Grinders used to have a low life expectancy on average, as they died early of silicosis as a result of the stone dust that got into their lungs. Around 1900, wet grinding based on the Sheffield model was believed to drastically reduce the health risk. However, as Ludwig Teleky, one of the leading occupational physicians, proved in the 1920s, wet grinding actually increased the risk, as the water dispersed the fine dust even more intensively, right into the alveoli. This was the first confrontation with the risk of fine dust!

steam power and remained - at least formally - independent. In dyeing and textile printing, manual skills were still important at the turn of the century.[153] Manual labor also remained competitive in plush and silk weaving until the end of the 19th century. Glassblowing by mouth continued into the early 20th century, and the quality of the glassware depended more on the skill of the glassblower than on advances in furnace technology.

In the dramatizing description of the progress-enthusiastic Bernal, Nasmyth's steam hammer "shattered once and for all the tradition of Vulcan's forge; the building of machines ceased to be a matter of human scale and required machines themselves". But machine tool construction in particular, which is considered the core of mechanization for good reason, retained distinctly artisanal traits throughout the 19th century. Some of it even survived the "Americanization" push of the early 20th century. As late as 1950, the Gildemeister director Grautoff remarked

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at a supervisory board meeting: "Machine tool builders are not workers in the usual sense, but rather artists whose joyful cooperation is the first prerequisite for success. "[154] On the user side, however, machine tools led in part to the decline of manual labor cultures. Until the end of the 19th century, however, the fitting of the manufactured individual parts still required skilled manual labor; in their early days, machine tools were characteristically called "auxiliary machines".

Progressive industrialization created a number of new niches for the skilled trades. There was a particular need for skilled craftsmanship in some production processes that had only emerged as a result of industrial development, while traditional mass trades such as tailoring, shoemaking and carpentry were hit hard by mechanization in the late 19th century. At the end of the 19th century, it was possible to recognize a general regularity in the fate of the various trades: Where mechanical mass production was applicable, there was no salvation for the independent crafts; but where the products of the crafts

"ever-changing, adaptable to the respective need", the trades could "have their advantage precisely through the flourishing of large-scale industry".[155] With growing prosperity and industrial level, there is by no means only a trend towards standardization, but at least as much one towards increasing differentiation of needs.

Under such conditions, artisanal forms of work also survived or emerged within large-scale industry. In the Krupp cast steel factory, up to the turn of the century, "the need to constantly produce new individual pieces, varying greatly in shape and size, repeatedly gave rise to open problems", the solution of which required the experience of the master craftsmen and the "Kruppianer" regular workers. The production of the caisson tubes also required "very skilled workers". The puddling process for steel production, which was by no means immediately superseded by the Bessemer process, but rather experienced its greatest expansion in Germany in the 1870s, was, technically speaking, highly manual: success was decisively influenced by the skill and experience of the puddler. The art of puddling was a trade secret and was deliberately only verbalized very imprecisely.[156] Even the old craft-like crucible process of steel production persisted in the era of "high-speed steel" after 1900 for certain special steels.

After the pioneering mechanic of the early 19th century had risen to become a trained engineer, the industrial mechanic, who had to put the engineer's drawings into practice, emerged as a new profession with all the elements of a highly skilled trade. As a result of the increasing division of labor, a locksmith allegedly knew "at the beginning of the 19th century

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only a tenth of what a locksmith had to know in the middle of the late (18th) century"; by the end of the 19th century, on the other hand, repair work again gave rise to the need for broader training.[157] Even in the 20th century, the working machines in locksmiths' workshops were "more of a support for manual labor than a substitute for manual labor". Until the 1920s, automobiles in Germany were largely manufactured using manual methods, even in areas where manual labor was not used.
"large series" was mentioned. At Daimler, there was a kind of "federal system of independent republics of master craftsmen". The car mechanic became the most successful new trade of the 20th century. Blacksmithing, often a poor trade in the old wagon, hoof and nail smithies, was given a new future in the automotive industry.[158]

In the early days of the Siemens company, when it was "still a mechanics' workshop and not a factory", the Siemens brothers repeatedly found cause for annoyance at the freedom of craftsmen that their mechanics, the "gentlemen artists", took for themselves. In 1847, Werner Siemens complained that the mechanics were spoiled for "energetic and one-sided" work with their "artist's sloppiness" and the style of work they were used to in precision mechanics. Since setting up his design office under Hefner-Alteneck in 1867, he went there almost every day, but only rarely entered the workshop. Under Hefner-Alteneck, an avowed opponent of "master craftsman rule", "all practical experience was suppressed, indeed all personal opinion in design matters was suppressed", as a former master craftsman complained in his memoirs. Siemens partner Halske, on the other hand, himself the type of craftsman technician who "may have wanted a handsome workshop, but by no means a factory", used to defend the "artists". His "artisan" attitude was not antiquated in every respect; he advocated that the company consistently specialize in the electrical industry, while the Siemens brothers sometimes speculated in other directions.[159] The technical specialization stemmed more from the craftsman mentality than the inventor and entrepreneur mentality.

When Siemens entered the mechanical engineering sector with "Kraftstrom", it was more dependent than ever on recruiting its workforce from the skilled trades. Until then, this had been done without any problems in the Berlin metal industry, but now there was a bottleneck and the company learned to appreciate the training services of the skilled trades. After the turn of the century, the company felt compelled to take apprentice training into its own hands. Looking back, the indiscriminate recruitment of unskilled "human material" from the "human sands of northern Berlin" seemed simply "terrible".[160]

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Contemptuous remarks about craftsmen were part of the style of the rising engineering profession; a Berlin engineer complained to Siemens in 1871: "[...] the noblest and most beautiful things are left almost entirely to the brutal hands of the lathes and hagglers." The striving for the top led to a sharp need for demarcation against the "crude", inhuman mastery in the factories, which stood in the way of the engineers' advancement. But even at the end of the 19th century, the foremen in many machine factories still had a "The overthrow of the master craftsman system was the declared goal of scientific engineers at the turn of the century. Until then, the engineer had primarily been a draughtsman; but the more design became routine work and the methods of mass production gave rise to the call for "production-oriented" design, the more engineers strove to bring production under their control. This was linked to the rationalization trend of the time, which pushed back the traditional workshop structure in large-scale industry in favour of the production flow.

And yet it would be wrong to see the growing subordination of execution to planning, of practice to construction, as the universal principle in the modern development of production processes: Practical experience in technology could only ever be developed to a limited extent. Engineers starting out in industrial companies repeatedly found that experienced skilled workers could do everything better. In 1907, a manual for engineers advised: "The young engineer or technician will never master the manufacture of machines as well as the master craftsmen, so it is recommended that he takes advantage of their experience and does not play the superior role." Even more recently, a Japanese expert on Germany remarked that the "traditional master craftsman system, which had long contributed to the German economic miracle" was still valid and was "hardly questioned".[162]

One of the main areas where "scientification" and mechanization reached their limits for a long time was *agriculture*. However, it would be wrong to see this as a generally backward area compared to industry. The beginnings of mechanization and the introduction of scientifically based methods also began here in pre-industrial and early industrial times. On the other hand, peasant resistance to such innovations was not always due to traditionalist inertia, but in part to experience and reasonable skepticism. Nowhere did Liebig deploy his eloquence and self-promotion more extensively than when he wanted to convince farmers of the necessity of supplying mineral fertilizers from outside the farming economy. But not only the effect

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The German agriculture of the 19th century was characterized not only by Liebig, but at least as much by resistance to this chemical pope.

In the 1940s, Liebig, later famous as the founding father of organic chemistry, monomaniacally defended the sole value of mineral nutrients against organic substances and against the humus and nitrogen theories, which at the time were not based on exact science, but "only" on experience, and behind which he sensed the hated natural philosophy and the belief in a world of life beyond the chemist's grasp. However, when Liebig's own experiments with his mineral fertilizer repeatedly failed, "the scornful laughter about the first artificial fertilizer [...] roared through the whole of contemporary literature" (Schnabel).[163] In the period that followed, Liebig's angry polemics against the mixed sewer system, which removed the excrement from the field, reveal that he no longer trusted that he could replace natural fertilizer with chemistry.

Over the years, Liebig corrected his initial one-sidedness; but for decades, the fertilizer research he founded was more at home in England than in Germany. Within Germany, densely populated Saxony, which was particularly dependent on the intensification of agriculture at an early stage, led the way. Even independently of Liebig and in contradiction to his theory, artificial fertilization increased, for example with Chilean guano and local bone meal; in the 1960s there were around 600 bone mills in the German Customs Union. It is ironic that nitrogen fertilization, of all things, which Liebig had long ignored, later paved the way for scientific chemistry in agriculture. However, there was a con- vergence between Liebig's teachings and the interests of the sugar beet and potash industries.[164] Sugar beet became the most intensive land use of the time, and it created a compulsion for artificial fertilization.

Beet sugar meant a kind of industrial revolution for some North German agricultural regions, led by the Magdeburger Börde: not only through the factories, but also through the transformation of agriculture itself; because as the connection between cultivation conditions and sugar yield became clearer, the factories prescribed seed and fertilization, cultivation, care and harvesting methods to the beet-supplying farmers. The foundations of beet sugar production had already been laid in the 18th century, and it experienced its first upswing during the period of the Continental Blockade; however, it was only after a long period of development extending beyond the middle of the century that the cheap mass production of a product of almost equal value to cane sugar was achieved. According to Liebig, the beet sugar industry had "almost achieved the impossible; instead of a greasy sugar that tasted like beet, they now produced the most beautiful refined sugar", and that with

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steeply increasing sugar yield. At the beginning of the 19th century, the yield had been three to four percent; the diffusion process introduced around 1865 made it possible to almost completely desugarize the beets and transition to mass processing. In the view of Williams, the British Cassandra, who warned of the "German danger", there was hardly anywhere at the end of the 19th century that Germany had such absolute dominance as in sugar production.[165]

In terms of area yield, German agriculture became the most intensive agriculture in the world before 1914, surpassing even the English model. However, it was characteristic of that time and even of the first half of the 20th century that modernization strategies, in contrast to American and German developments since the 1950s, were primarily aimed at increasing the yield per unit area and not so much at increasing labour productivity. Before 1914, the capital intensity of German agriculture was far lower than that of the American, British and Belgian agricultural sectors. Until the turn of the century, small farmers in south-western Germany still preferred the sickle when harvesting grain in the old way in order to minimize grain losses. Sugar beet cultivation, which was spreading in northern and eastern Germany, even intensified manual labor in the fields and, when competition from industrial wages caused problems for agriculture, led to the mass recruitment of Polish agricultural workers - to the anger of the young professor Max Weber, who called for a stop to the immigration of Poles to eastern Germany in his inaugural speech in Freiburg in 1895. As late as 1919, it was said that the "Polish question" was "merely a root crop issue".

In 1851, the first agricultural research center was opened in Möckern near Leipzig.

Although farmers were long suspicious of the innovations of their scientific advisors, experimentation became common practice in the agricultural sciences earlier than in mechanical engineering. Plant breeding, analysis of plant growth conditions and animal feed trials were more important than mechanization experiments.[166] The steam plough, in which the plough was pulled back and forth with a rope by two locomotives standing at the edge of the field, was made famous in literature by the writer-engineer Max Eyth, the founder of the German Agricultural Society (1885), and the German machine industry was heavily involved in this business; but Eyth achieved his steam ploughing records in America and with the Khedive of Egypt. In Germany, never more than one percent of the arable land was cultivated with steam power. Even among the largest landowners, who owned over 1,000 hectares, only a tenth had steam plows in 1882.

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The first major machine to become an integral part of German agriculture was the threshing machine, which was initially driven by a gin. Propagated since the end of the 18th century, it only became widespread at the end of the 19th century, initially on large estates. Its breakthrough came with "great difficulty", as it was initially rejected by many farm workers; the extremely labor-intensive threshing had previously been an important source of livelihood for entire daily wage classes. Technical simplifications were also necessary for the threshing machine to become popular with German farmers.

German farmers in the 19th century were more willing to accept sowing machines than harvesting machines; Alban earned a large part of the money he had to pay for his high-pressure steam machines with these horse-drawn machines.[167] In and of themselves, a whole range of agricultural work processes were relatively easy to mechanize; however, until the early 20th century, only animals and people were available to drive these "machines". Powerful farm horses were one of the most important "innovations" of the 19th century on farms that had previously mainly used oxen as draught animals - "horsepower",
"horsepower", still retained its literal meaning as a unit of measurement. Increased use of machinery required increased horse husbandry; the number of horses in German agriculture was on the rise until the 1920s.[168] Even outside of agriculture, the industrial demand for power not only stimulated the further development of the steam engine, but also horse breeding.

Steam engines only benefited large-scale agricultural operations; in this respect, mechanization reinforced the divide between large-scale farmers and small and medium-sized farmers. However, mechanization based on human and animal power was much more widespread until the 20th century, and here the medium-sized farm, which maintained a balance between arable farming and livestock breeding, could even have an advantage over the large farm. Many regional open-air museums of farming culture provide a vivid picture of this phase of industrialization, which already seems archaic today. It was easier to introduce mass production methods in the manufacture of these simple devices than with complicated machines. The Leipzig agricultural machinery company Sack produced its millionth plough in 1904, the Ulm company Eberhardt its 700,000th; the Württemberg scythe factory Haueisen, the most important company of its kind in Germany from 1865, produced 595,000 scythes and sickles per year. Horse-drawn harrows, hand-operated chopping machines and hand mills were among the most important innovations on the farms of the time. Single-horse-powered harrows in particular were made entirely of iron early on, while larger ones were still made of wood; the harrows in turn enabled the introduction of other machines.[169]

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The lifting of the mill ban in the 19th century not only led to a boom in windmill construction - the suitable sites for water mills were usually already occupied - but also to a proliferation of hand mills, which had previously been persecuted by prohibitions. Until the beginning of the 20th century, technically improved hand grist mills were more of a problem for northwest German wind and water mills than the emerging steam mills. They were the first to introduce the roller mill, which revolutionized grinding technology. Attempts to increase the capacity of the windmill did not get very far; as a Danish study found in 1905, "once a certain size has been reached, the mill becomes relatively expensive the more it grows externally". Denmark, which is more exposed to westerly winds than large parts of Germany, was quick to develop the windmill into a steel wind rotor and, unlike the megalomaniac German wind power prophet Hermann Honnef, followed the principle of "small is beautiful". For a long time, this approach was more successful than the drive for size; *economies of scale* only existed in theory.[170]

In the era of steam power, the mechanization possibilities of German agriculture appeared to be exhausted at the end of the 19th century. In 1893, the Hohenheim Agricultural Academy refused to establish a chair for agricultural engineering, as "the construction of the most common machines can be considered almost complete" and in a country with predominantly smallholdings, "the number and type of machines used in agriculture is limited by the nature of the matter anyway".[171] It was only with the diesel engine, the development of machine types for medium-sized farms and the pressure of the labour shortage that the mechanization of agriculture began to move forward again in the 20th century.

The *construction industry*, one of the largest growth sectors of industrialization, and the associated timber industry were also areas where the limits of mechanization became apparent in a way that was characteristic of Germany. The state building officials were originally the prototype of the professionally trained, status-conscious technical elite par excellence, which stood as a role model for the new groups of technicians emerging in the 19th century. This stands in strange contrast to the fact that the building process retained its artisanal character well into the 20th century. Outside of the state building sector, civil engineers were therefore unable to assert a claim to leadership: "The expert for private construction was and remained the master builder." In the second half of the 19th century, a tense relationship developed between civil engineers and mechanical engineers, who were also pushing for academic dignities and leading positions in major state projects; the status interests of the

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Civil engineers were opposed to the intrusion of machines into construction operations.[172]

Another case was civil engineering and the production of building materials: in brickworks, cement works and sawmills, mechanization sometimes reached large-scale dimensions. The emergence of new building materials - steel, concrete, reinforced concrete - brought an industrial element to construction operations. In Germany, steel construction favored the separation of architect and builder, which was expressed in many railroad station buildings in the contrast between the reception building and the platform hall. Many German master builders in the 19th century, more so than their English or French colleagues, had a
"disturbed relationship to the material iron"; more than in other countries, a separation developed in Germany between the architectural and engineering professions. The fact that an avant-garde streak was only weakly developed in German architecture until the end of the 19th century also had an effect on technology. The academic ambitions of German architects in the 19th century promoted historicism in architecture. In contrast, the reinforced concrete construction method with its striving for curved, seemingly weightless forms, a French invention, was still considered typical French architecture in the 1920s. In 1901, the then chairman of the German Concrete Association, Eugen Dyckerhoff, gave his colleagues in the association the advice, which is not entirely unfounded from today's perspective: "If you want to sleep peacefully, leave the iron out of the cement [...]" Something else was the massive unreinforced concrete, which had been permitted in German fortress construction since 1873 and became the first object of standardization at a national level.[173]

German architects and engineers of the 19th century did not show much willingness to experiment with timber construction either. Wooden long-distance construction technology developed primarily in England and the USA, where many wooden railroad bridges were even built in the 19th century that made German travelers "tremble". On the other hand, German architects excelled in the theory of half-timbered construction.[174]

In Germany, wood as a building material retained a traditional trait into the 20th century under the influence of homeland protection and historicism. In shipbuilding, wood was abandoned only hesitantly; unlike in England and France, shipyards in the 1960s still "clung to the prejudice that iron as a building material was contrary to the natural order". In the transition to iron construction, the decisive impetus subsequently came from the warships. But as late as 1880, the president of the German Shipbuilders' Association asserted that "the time for building iron troughs" was over.
"soon over": "We will get to build wooden sailing ships again in the future." The 19th century was not just the age of the steamship,

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but with the use of iron elements also brought the technical high point of sailing ships. The strong position of the ship's carpenters, which was only broken by iron shipbuilding, is an example of how the autonomy of work was maintained with wood, a material that did not recognize a strict division between planning and execution.[175]

Technical traditionalism of this kind is not synonymous with backwardness. The same applies to the hesitant mechanization of timber processing outside the sawmill and to the long-lasting aversion to the circular saw in the German timber industry of the 19th century, which introduced the technically advanced rotation principle to timber cutting, but produced a lot of waste and was "one of the most dangerous of all machines". Even among German sawmills, growth in size was generally limited; even smaller operations that specialized in certain types of wood and markets had their advantages. There were still obstacles to mechanization in the timber industry that stemmed from regional conditions and the nature of the wood.[176]

8. Technization of the idea of progress and safety management: a founding era of modern environmental policy and a great era of pseudo-solutions

In construction technology, the historical origin of engineering, "safety" was a clear standard with a clear addressee: Safety from collapse was meant, and the blame for such an accident lay with the construction manager. Almost complete safety was possible. All this was different with machines. There was no such thing as safety in the full sense. Nevertheless, around 1878, the term "safety" came into official use for "hazard reduction": there, it was more of a euphemism.

In the case of accidents involving machines, it was always easy to blame human error. But even progress enthusiasts of the 19th century sensed the unsatisfactory nature of this attribution of blame and recognized that "the higher technology and the greater complicity of the machine" was the real cause of many bad accidents, "because nature, which is subjugated by man, immediately punishes every human error severely".[177] The ideal of a "error-friendly" technology was already tangible in the early days of industrialization, especially as there was a fundamental mistrust of complicated technology back then more than in later times.

With the transition to higher pressures, the steam engine immediately raised the issue of safety as a central topic. Boiler explosions were shocking.

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events and the ever-present threat of the steam engine.
"Nowhere is more conscientiousness required than where man with his weak powers sets himself up as the master of a giant, as steam is" - the not yet lost sense of human measure sharpened the awareness of danger.[178] Especially when the steam engine was conventionally understood as the prototype of industrial technology, the idea of great danger was associated with modern technology, and it was obvious to call for strict state supervision.

Following the French model, steam boiler safety in Prussia was initially kept within the competence of the state.[179] However, it was precisely here that the doctrine that the best guarantor of technical safety was the collective interest of an industry capable of joint action subsequently prevailed; after all, in the prevention of boiler explosions, the interests of the company coincided with the interest in occupational safety and environmental protection. In this respect, the safety issue was deceptively simple. With steam boilers - as with nuclear power plants over a hundred years later - there could be disagreement as to whether the ideal of safety consisted in preventing explosions or in strictly limiting the consequences of explosions. In 1831, when the complete prevention of explosions still seemed hopeless, Alban justified his tubular boiler with the criterion: "Only those boilers can really be called safe that do not cause any damage even if they burst. "[180] Limiting the consequences of an accident by design as a way out for technologies that could hardly hope for complete inherent safety: this later nuclear safety philosophy also existed at the beginning of German industrialization.

The risks of the vast majority of machines only affected factory workers, but the locomotive brought the public face to face with the steam engine in an exciting way. The railroad immediately made technical safety a public issue, especially in its early days, when it made people tremble and the power of habit had not yet dulled the public. "It is really a flight," wrote the liberal politician Thomas Creevy in 1829 after a ride on the Stephen- son locomotive, "and it is impossible to get rid of the idea of instant death to all in the slightest accident." Early neurology exaggerated the traumatizing effect of railroad accidents on the nervous system.[181] Railroad accidents remained high-profile sensations throughout the 19th century, causing administrative pressure to act, much in contrast to 20th century car accidents, which became individual misfortune and routine everyday news - there has been not only progress but also regression in safety awareness over the course of modernity. Over the course of time, the railroad has come up against a major inherent

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The technical perfection of this closed system resulted in a high level of safety. With steel rails, automatic brakes and mutually blocking signals, a relatively simple and plausible technical safety concept emerged in principle, even if it was not able to completely eliminate the human factor as a source of insecurity. Then there was the eternal dilemma of technical safety precautions: The electrical signaling system provided a feeling of deceptive safety and thus tempted people to drive at higher speeds. The worst accident disasters only happened in the era of electric signals!

The transition to the mass use of coal around the middle of the 19th century marked a profound turning point not only in economic history, but also in environmental history: by tying industrial dynamics to a non-renewable resource and by the unstoppable increase in CO_2 pollution of the atmosphere from then on. The global ecological consequences of this process could not be grasped at the time; however, the fact that coal smoke was harmful had been a widespread conviction based on sensory perception since time immemorial. The pernicious effect of smelter smoke on vegetation was clearly demonstrated by farmers in the vicinity of smelter complexes, and this was also confirmed from the middle of the 19th century by research carried out by the Tharandt Academy of Agriculture and Forestry near the Freiberg mining area. The realization came remarkably quickly that there was no "harmlessness limit" for the pollutants, meaning that a wide distribution through high chimneys only caused a wide dispersion, but did not prevent damage.

However, there were lower limits below which it was no longer possible to provide exact causal evidence of damage. In the late 19th century, the concept of the *"tolerance limit"* prevailed in trade supervision, which legalized environmental pollution and gave the control a semblance of exactness, even if in reality it was more a limit of knowledge. In addition to the policy of high chimneys, which ex- ternalized and, as it were, socialized environmental pollution, there was also a requirement for factories to reduce smoke nuisance in the neighbourhood by closing windows: Environmental protection at the expense of occupational health and safety, especially when agrarian interests were involved. "Studies on the effects of smelter smoke on humans fell far short of those on cattle." (Arne Andersen)[182]

The chemical industry was identified as one of the worst environmental polluters remarkably early on, when small businesses still predominated. Soda factories using the Leblanc process polluted their surroundings with toxic hydrogen sulphide, the penetrating stench of which provoked local residents. The toxicity of chlorine gas had already been recognized by the

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Bleichen. When Friedrich Bayer received the license for his first chemical plant in Barmen from the Düsseldorf government in 1854, 23 citizens of Barmen protested because of the health risks they feared. While the Royal Technical Deputation for Industry tried to dismiss the objection, the Scientific Deputation for Medicine declared the concerns to be partially justified. A fierce expert controversy began, in which people thought they had already been transported back to the ecological era; much of what is now classified as "environment" was then classified as "hygiene" and was the responsibility of the medical profession. The medical deputation stated "from its own experience" that "manufacturers are convinced that once they have obtained a concession, they are not responsible for any further damage, a belief that is highly dangerous for the public, for example, in the case of those who manufacture toxic substances." Amazingly, the Prussian Minister of Trade followed the medical deputation without reservation, not the technical deputation, and prohibited the manufacture of iron pickling and blue powder because of the toxic gases produced.

The early aniline factories were even more notorious among the population as "poison factories". In 1866, the *Social Democrat* reported on how the fire department had
"aniline poison factory" - "the scourge and horror of the whole area" - was quickly dismantled until "only the paint and arsenic residues" remained,
"where the terrible factory had its hideous asylum". The aniline red of the time contained arsenic. Around 1860, in the early days of the Geigy company, the Basel Sanitätskollegium noted that aniline dye production was characterized above all by the fact that "it actually works with poison and poison is its life element; that it communicates this poison in solid, liquid and gaseous form to the soil, water and air and thus, if strict limits are not imposed, brings about a slow but certain destruction of all normal health conditions". "There is probably no industry that enjoys so little sympathy among the citizens as that of the chemical factories," wrote the mayor of a municipality in Wuppertal in 1888. The paint factories, the worst water polluters, demanded particularly clean water themselves and therefore preferred to settle on the upper reaches of the rivers. In 1895, one landowner expressed his indignation against the entire Elberfeld chemical industry in a petition: "As far as I know about the conditions of chemical factories in Germany, nowhere have they acted so frivolously and unscrupulously against their neighbors as here in Elberfeld." Protests of this kind were one of the reasons why the Bayer company moved from Barmen to Leverkusen at that time, although from the Wuppertal's point of view it was "at the end of the world" and the workers were reluctant to move there.[183]

The chemists themselves were only too well aware that their profession was by no means

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was harmless, but an almost soldierly attitude to danger

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required. Charles Mansfield, one of the pioneers of aniline chemistry, fell victim to a benzene fire in his laboratory in 1856. Liebig, who, as he said, discovered "a fulminating copper, a fulminating iron and a fulminating zinc", experienced numerous explosions during his experiments; his left eye is said to have been severely damaged by an explosion; "hair-raising, fabulous stories" were told about his investigations into "fulminating acid". He took "great offense" at his assistant when the latter "showed a certain amount of bias in carrying out an experiment that was not exactly harmless". Even the explosions only strengthened Liebig's popularity. But no one could imagine that chemistry was a harmless discipline.[184] The environmental pollution caused by the chemical industry was by no means viewed with the same benevolence as the dangers of laboratory experiments, in which the researcher himself bore the main risk.

The history of the threat to life and health caused by technology and the resulting awareness of crisis has so far been researched mainly in isolated cases; the historical processes and epochs involved can only begin to be surveyed. However, it can be clearly seen that industrialization at the stage at which it gained its signature through steam power and the growing agglomeration of companies and workers in the expanding factory towns - based on the mass production of coal - initially led to a situation that was perceived by many as crisis-ridden for decades; the social crisis could hardly be distinguished from the environmental crisis and the threat to health. In England, this phase occurred in the early 19th century, in Germany in the decades after the middle of the century, with a peak in the 1970s, when the Gründerkrach intensified the general awareness of the crisis. At the time, canalization plans by Rhine bordering towns threatened to turn the "German river", which the quasi-national anthem "Die Wacht am Rhein" called upon people to defend against the French, into a cesspool. The uprising was fierce at times and led to a rigid decree in Prussia in 1877 that banned the discharge of municipal wastewater into public waters. If it had not soon been undermined by limit value regulations, it would have steered the municipal disposal system in a different direction. However, it was made without the engineers and was technically impossible to implement at the time.

Serious accidents in factories and especially in mines also became was perceived as a political issue at the time. The impetus for this came not least from the growing labor movement. Alluding to two mining disasters of the time and the famine in East Prussia, the *Social Democrat* wrote in 1868: "But in the hearts of the workers, in the hearts of the millions

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Disinherited, the three words will be deeply imprinted: Lugau - East Prussia - New Iserlohn!"[185]

Towards the end of the century, however, the general consciousness - in the middle classes as well as in social democracy - had fundamentally changed. The confidence that technological progress, if only given free rein, would remedy much of the damage caused by industrial technology itself became the prevailing doctrine, albeit not unchallenged, in line with the salvation message of Wagner's "Parsifal": "Only one weapon is good: the wound closes/the spear only that struck it." Several technical and political developments had led to this optimism. Sewerage systems, the "hygienic revolution", the increasing spread of "clean" electricity, advances in technical occupational safety, the
"smoke-consuming" combustion, in the utilization of previous waste materials by the chemical industry, justified this optimism, but also a reduction of problems that brought the solution within reach: by setting limit values for air and water pollution, reducing many environmental problems to questions of external cleanliness and only tackling harmful effects in the area of what can be precisely proven. Certainly, there were quite a few genuine advances in occupational safety and environmental protection, and the reformist energy of that time is still exemplary today. However, many of the supposed successes were merely a matter of invisibilization, shifting and reduced perception of problems: pseudo-solutions that concealed the fact that the health and environmental risks of technology were growing into new dimensions at the same time.

The environmental crisis in the first phase of high industrialization was perceived particularly starkly as a crisis of water supply and disposal and as a crisis of housing hygiene. For this reason, *"urban technology"* and *"urban hygiene"* were of outstanding importance in the mechanization of technology impact management. England was the great role model until the end of the century; but unlike there, in Germany, based on English experience, it was possible to tackle sewerage systematically and under municipal control from the outset. In Berlin, where the only "receiving waters" were the Havel and Spree and not the wide Thames as in London, urban drainage had to be planned much more precisely and systematically at an early stage than there. When operated consistently, the sewer system was a large-scale system technology and in this respect was only comparable to the railroad in the 19th century. If a municipality decided on a particular route, this had far-reaching consequences and blocked other routes.

The disputes over urban waste disposal systems are among the most heated controversies in the history of science and technology in the 19th century. As never before, the municipal waste

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The decision of the local authorities here depended on experts; the scope of the problem encouraged the formation of expert groups. It was a question of whether the alluvial sewer system (mixed sewer system), which flushed away the solid waste together with the liquid waste, was preferable, or another system that allowed the solid faeces to be used as fertilizer for agriculture as before. At the forefront of the partisans of alluvial sewerage was the Frankfurt local politician Georg Varrentrapp, the "Luther of hygiene in Germany" and pioneer of the water closet. The most prominent campaigner on the opposite side at times was Liebig, who condemned mixed sewerage as a treacherous English machination that would destroy the fertility of the German soil, just as England in general, which had ground the bones of the German freedom fighters on the battlefields of Leipzig and Waterloo into fertilizer, was "like a vampire" "clinging to the neck of Europe", indeed the world, and sucking out its "lifeblood".

From an ecological point of view, the criticism of the combined sewer system was well-founded; the controversy was initially not without effect, especially as the sale of faeces to farmers had been a source of income for house owners. From the outset, however, the combined sewer system had the appeal of a large, uniform solution that quickly and thoroughly eliminated all stench. While the opponents propagated different systems, but none of them were able to achieve a technical maturity that met modern requirements, the supporters of the mixed principle concentrated all their efforts on *one* system. Here, a broad and stable alliance of local politicians, hygienists and building officials was formed, which was able to create a "state of the art" that ultimately pre-structured the political decisions. By the end of the century, the victory of alluvial canalization had been decided. It was precisely the artificial fertilizer propagated by Liebig that promoted this victory, as it devalued faeces as a fertilizer and weakened the support of the separating fraction among farmers and landowners.[186]

At that time, however, we had to learn that the most perfect sewer system was a questionable advance if it was not connected to a *sewage treatment plant*; this was especially true for cities on the plains and on the coast, where the removal of wastewater from the sewer system directly into the rivers was slow and incomplete. The conflict between the major schools of hygiene played a role here: the "miasmaticists" attributed the epidemics to soil contamination, the "contagionists" to bacteria. Only the latter doctrine gave rise to the postulate: no sewage system without a sewage treatment plant. In the late 19th century, this became a dispute between Munich and Berlin: between Max von Pettenkofer and Robert Koch. If the people of Munich discharged their wastewater into the Isar, they were rid of it; in the

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Berlin, on the other hand, the sewage threatened to spill back into the water supply. Hamburg, which in 1848 had been the first major German city to introduce a comprehensive sewerage network and enjoyed the image of an exemplary clean city, but relied all too much on the cleanliness of the Elbe, fell victim to the last major cholera epidemic in Germany in 1892, which demonstrated the disastrous effects of inadequate water purification.[187] This settled the dispute between the schools; in 1901, the unfortunate Petten- kofer, who had earlier, in order to ridicule his great rival - or was it out of a secret longing for death? -had publicly drunk a glass of cholera bacteria from Koch's laboratory and survived.

However, a satisfactory "state of the art" for sewage treatment plants was a long time coming. Chemistry did not provide the hoped-for patent solution; the different composition of wastewater required treatment technologies that were adapted to local conditions and yet could never keep up with the ever new pollutants. From the seventies onwards, more and more cities - partly under pressure from above - began to set up sewage fields whose sewage sludge was to be used for arable farming. The results of these experiments were inconsistent and sometimes disappointing, but the trickling fields nevertheless supported the illusion that we were well on the way to a final solution to the disposal problem. This optimism was possible because the main attention was focused on faeces and little attention was paid to the fact that industrial wastewater was increasingly spoiling the fertilizing value of sewage sludge, although this could have been known better even then.[188]

The huge water towers, designed in the late 19th century like the railroad stations as representative monumental buildings with historicist style elements and perfected with reinforced concrete after the turn of the century, demonstrated the newly acquired supply function of the municipalities, which were given a technical basis, so to speak, with pipe systems. The "public baths", often built in elaborate architecture from the 1990s onwards, helped to popularize the "hygienic revolution". Around 1900, hospitals were finally shaking off the old smell of the poorhouse and becoming monumental, lavishly equipped laboratories of mechanized medicine. Milestones were the introduction of anesthesia and antiseptic surgery as well as X-ray and bacteriological diagnosis. The "X-rays" discovered by W. C. Röntgen in 1895/97 became established in just a few years, as people were initially unaware of their danger and then, in their enthusiasm for the new transparency of the human body, did not want to know anything about them.

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Figure 18: "The radiologist shoots for death with X-rays": etching by Ivor Saliger (around 1921), who had a penchant for images in which the doctor saves a naked woman from the bone man. The picture contains a good deal of propaganda for the time: in the early days, X-rays were still blurred and of limited diagnostic value; and the risk of cancer being caused by the often careless use of X-rays at the time was presumably greater than the chance of not only diagnosing cancer but also curing it using X-rays.

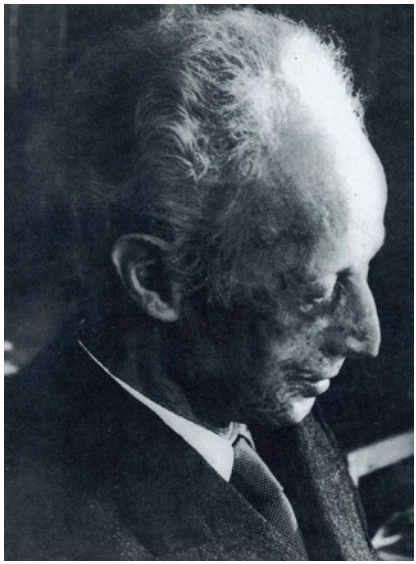

Figure 19: Picture of the X-ray technician and technical philosopher Friedrich Dessauer (1881-1963), who suffered severe radiation damage during the development of X-ray machines. He later wrote that almost all of his employees "died in agony from radiation burns". However, he professed to believe that technically caused damage was a sign of a still imperfect state of technology and would disappear as it was perfected. He, who was driven into exile by the "Third Reich" because of his Jewish origins, believed in a "Fourth Reich" of perfect and therefore humane technology.

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Kautsky referred to the connection between the development of technology and hospitals in a way that was typical of social democracy at the time: "Just as modern productive technology can only fully develop its beneficial effects in large-scale operations, so too modern medical technology can only develop in large medical institutions." Not to forget: The mechanized hospital was music of the future back then, not reality! The numbing of the agony of surgery through anesthesia contributed not a little to the belief in the philanthropic, even redeeming character of scientific-technical progress. The surgeon's art now no longer consisted primarily of operating as quickly as possible, but was methodically developed and supported by a growing range of technical instruments. Surgery became so technically perfect that it was possible to forget that it was "always an act against nature". Bacteriology, the great medical achievement of the late 19th century, which was made possible by advances in optics and dyeing technology, displaced a more complex view of the causes of disease that also included the way of life and work, and crossed the link between medicine and social policy that the perception of crisis in early industrialization had challenged. The "spittoon fanatic" replaced the medical social politician. In this respect, the high point of "industrial hygiene" around 1900, which manifested itself in widely acclaimed exhibitions, rather signified the end of an era.[189]

Not only the water pollution, but also the *"smoke plague"* over-
In the late 19th century, this became a threshold in many cities. From the 1990s onwards, electrification promised a remedy here, as centralized power generation and electricity transport over long distances made it possible to build the "power stations" outside the cities, so that city dwellers could no longer see the smoke they emitted. In addition, since the 18th century there had been the ideal of "smoke-consuming", "smokeless" firing and the idea that firing systems would become "clean" if they were brought to the highest technical perfection. *"Smoke means waste!"* was the battle cry of the anti-smoking movement in the USA, where, under the conditions of civil society, the fight against the "smoke plague" was staged more as a public battle than in bureaucratic Germany; German engineers took a similar view.

The issue of "smokeless incineration" was one of the most important issues in the nineties.

"among the most talked about in technology and in public economic life". This ideal originated at a time when it was not yet known that combustion is oxidation; for a century, however, it should have been clear that the formation of carbon dioxide in fossil firing systems is unavoidable in principle. The "senseless hunt for smokeless combustion" (Spelsberg) concentrated on the visible smoke components, soot

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and ash; successes were achieved here in the late 19th century. However, if it was claimed that the reduction of smoke always increased the economic efficiency of the company, this was not true in reality, and so the panorama of industrial cities was still characterized by smoking chimneys until the middle of the 20th century.[190]

Since the end of the 19th century, the most effective protection against smoke, at least for the upper classes of the population, was to divide cities into zones, within which the industrial pollution to be tolerated was measured according to BGB § 906 on the basis of "local custom". This legal situation offered the opportunity to push industrial companies out of "better" residential areas, while in the industrial districts the "customary local" pollution increased with each newly licensed company. The worst part of the environmental pollution perceived at the time was thus shifted to the lower classes.[191]

At the same time, however, it became popular to see the "social question" primarily as a housing problem. As such, it could have been solved technically: ideally by introducing mass production methods into housing construction. This was the goal of the young Walter Gropius; however, such efforts were limited by the technical conservatism of the construction industry. In contrast, the dream of the housing estate "in the countryside" gained increasing momentum. At the time, it was associated with utopias of an ideal community. In reality, this usually turned into suburban housing estates with less social contact than in the old cities.

The chemical industry, initially perceived as one of the worst environmental polluters and therefore all the more dependent on the consecration of science, was able to radically change its public image in the late 19th century and stylize itself as a branch of industry that used scientific systematics to make useful use of previous waste materials and contributed in its own way to the technical solution of the problems arising from industrial technology. Hydrochloric acid and sulphur residues, the worst evils of the soda industry and smelting processes, could be profitably reprocessed from the 1970s onwards. An expert opinion by Liebig assured that sulphurization was an excellent and flawless method of hop preservation and contributed to the ban on hop sulphurization issued in Bavaria in 1830 being lifted again (1858) and Nuremberg being able to develop into the most important hop trading centre in the world. The people of Nuremberg, however, had to put up with the yellow fumes from well over a hundred sulphur kilns.[192]

The transformation of coal tar, the dirty and smelly waste product of gas works, into bright colors was a particularly impressive example of the technical possibilities of waste utilization and one reason why the "Book of Inventions" proclaimed:

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Figure 20: Advertising brochure of the Gersonsche Müllverwertungsgesellschaft from 1925. In the course of the 20th century, it had to be recognized that the complete recycling of waste materials would by no means succeed automatically - as had been hoped at the turn of the century - in the course of the progress of the chemical industry, but that this industry itself would create disposal problems of a new kind. As you can see, waste recycling in a metropolis like Berlin began to become an industrial sector of its own kind as early as the 1920s, insisting on its own patents.

"There is no more waste. We can produce sugar from sawdust, rancid butter can be turned into a fragrant ether [...]; the fatty components carried away by the rinsing water from the wool washes are recovered and processed into lubricating oil or turned into excellent illuminating gas in the retorts of the gasworks."

An infinite process, even outside of chemistry? Musil's "Man without Qualities" muses: "Just as technology has long since made useful things out of cadavers, refuse, broken pieces and poisons, psycho-logical technology could almost do the same." Since the end of the 19th century, the chemical industry has made increasing use of coke oven residues; blast furnace slag

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became the basis of a branch of the cement industry, Thomas slag a sought-after fertilizer. All of this distracted from the fact that the environmental problems caused by chemistry were becoming increasingly complex and the chemical processes were inevitably producing more and more new by-products.

Towards the end of the century, the growing pollution of rivers by industrial wastewater became obvious. However, it was now said that industry was ultimately a thousand times more important than river fishing. Sometimes the farmers complained about river pollution, but the sugar beet industry caused large-scale water pollution on the part of the East Elbe landowners themselves. The ecology of the waters could no longer be defended by economic means. In 1911, the mayor of Elberfeld declared: "When the Wupper has no more color, we can pack it in; then there will be nothing left at all." In 1912, Duisberg could afford to brusquely reject a widely demanded Reich Wastewater Act, as - Duisberg said with brutal frankness - everyone knew "that the chemical industry cannot live without wastewater, and yet we are among those who create great economic value". What "pure water" is: the chemists' community now claimed to define this for itself, asserting at the same time that chemically pure water does not exist in nature anyway.[193]

In the 19th century *hygiene movement,* there was a tendency to see occupational safety and environmental protection as a continuum. Both areas were linked by the problem of emissions. Even in the early days of industrialization, it was recognized that chronic exposure to dust particles could pose an even greater threat to workers' health than the risk of accidents associated with machinery. Exhausters and other ventilation devices were at the heart of occupational health and safety efforts from the very beginning, as well as the exhibitions on "industrial hygiene" that boomed in the "new era" after 1890.[194] The hygiene movement established the norm of preventive health care; in this it was promising for the future. However, the concrete ideal of "hygiene" was often limited to cleanliness that could be perceived by the senses. With the water closet and the new detergents, hygiene created new environmental problems.

The social policy leading to the workers' compensation insurance of 1884, which was primarily a breakthrough for the idea of occupational safety, had at the same time blocked further-reaching efforts to intensify state industrial supervision and establish uniform technical safety regulations and replaced the principle of prevention with that of subsequent compensation - and even this only to a limited extent. Nevertheless, the employer's liability created indirect pressure to improve safety in the workplace.[195] One of the main shortcomings of the strategy adopted with accident insurance was that compensation was limited to accidents and was only paid in the event of an accident.

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chronic health impairments were disregarded. It was not until 1925 that eleven occupational diseases were recognized as requiring compensation for the first time; as late as the 1970s, over nine tenths of all applications for compensation were rejected.

The realization that occupational diseases exist was anything but new in the 19th century. The damage to the body caused by certain professions was particularly evident in the old society, in which professions were passed down through generations and professional groups were visually represented in guild parades. Lead, arsenic and mercury poisoning had been known from the mining industry for centuries. Ramazzini's opus on occupational diseases, first published in 1700, was still considered a standard work in the 19th century.

In industrial cities, on the other hand, where workers fluctuated and several stresses came together, it was more difficult to provide exact causal evidence of the connection between work and illness: a fatal circumstance at a time when science was only interested in what could be proven exactly. The rise of bacteriology also distracted attention from the occupational causes of disease. Silicosis and asbestosis were initially recognized as variants of

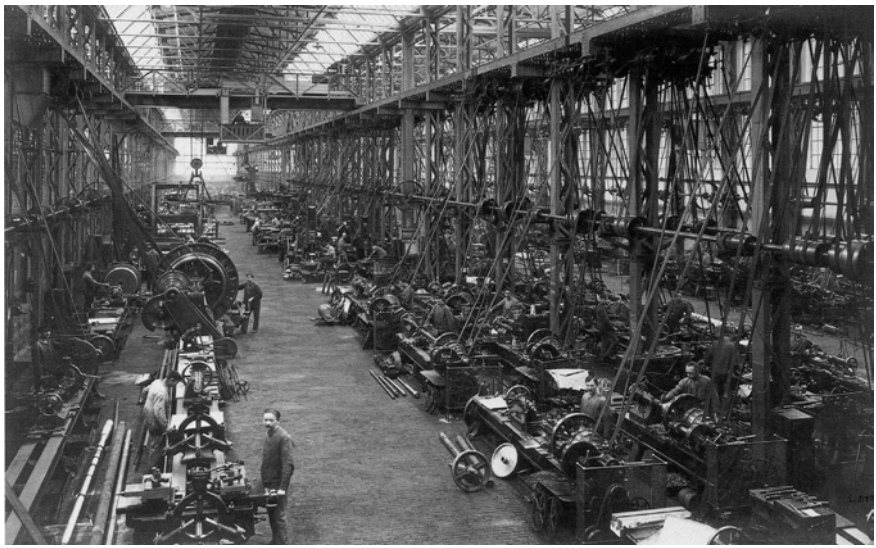

Figure 21: Essen cannon workshop in 1917, in the middle of the war. You can see several rows of transmission belts running close together from the drive shafts high up to the lathes. Before the introduction of the individual electric drive, the fast-running drive belts, which were often crowded together in factory halls, were one of the worst sources of accidents. "The warning posters depicting women scalped by the transmission or mutilated workers are legion" (Axel Föhl).

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of tuberculosis. It was above all a few undeniably extreme cases of health-destroying production methods that attracted the attention of trade inspectors and engineers in the late 19th century: for example, the phosphorus necrosis of match manufacturers, the insidious mercury poisoning (mercurialism) of mirror layers and the silicosis of grinders. In all cases, the decreed remedy was along the general lines of "hygiene" and technical progress and did not affect productivity. Nevertheless, general enforcement only took place after state intervention.[196]

At the German General Exhibition for Accident Prevention, which took place in Berlin in 1889 under the imperial protectorate, technology took the "lion's share" to a striking degree.[197] However, the practical value of the safety devices was generally impaired by the fact that they were devised by engineers who did not have to work with them themselves: in the case of safety, the downside of the separation of technical science and practical experience was particularly evident. One constant complaint was that many safety devices were not used in practice. The reasons for this are partly to be found in a general indifference and in the hindrance of work by safety measures, but partly also in the fact that many workers felt that dealing with risks was part of their own professional experience. When technical safety precautions were enforced, it was not uncommon for the willingness to take risks to increase at the same time: an effect that was as fatal as it was promising for the future. In the Ruhr district, the "safety lamp" led to miners being deployed in dangerous seams that had previously been avoided; the "safety explosives", which were prescribed by the mining authorities in 1902, made some mine foremen more reckless.[198]

At the end of the 19th century, occupational health and safety in Germany was

really exemplary on an international scale? It is interesting to compare the small iron industry in Solingen and Sheffield, which fought off the German-English competition in a highly regarded manner and whose grinders were exposed to silicosis, one of the worst occupational diseases to this day. As late as 1900, the statistics seemed to indicate that "the Sheffield grinder was getting older than the Solingen grinder". Unlike in Solingen, wet grinding predominated in Sheffield, which caused less dust, and the grindstone rotated away from the grinder rather than towards him; the Sheffield grinder was able to adopt a healthier posture at work than the Solingen grinder, and he exercised in his spare time. In Solingen, greater emphasis was placed on extraction devices and other "hygienic" precautions; a police order to this effect was issued in 1898. After a short time, these advances

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Gänzliches Verbot der Frauenarbeit an Holzbearbeitungsmaschinen, in Sägewerken und auf Holzlagerplätzen!

Figure 22: Touring exhibition in the Hygiene Museum of the AEG factory in Berlin (1912), with which the German Woodworkers' Association publicized its accident protection demands adopted in 1911. Cooperation between industry and employee representatives on accident protection had already developed in the German Empire; this is one of the historical origins of co-determination. German industry had already tried to make a name for itself at the Paris World Exhibition of 1900 with safety precautions for woodworking machines. These - with the circular saw at the forefront - were indeed among the worst sources of accidents: "interfaces" between man and machine in a very literal sense! As can be seen from the sign on the left, the woodworkers' association used the high risk of accidents to justify its demand for a ban on women working in the woodworking industry!

According to a report by a Sheffield doctor who visited Solingen in 1908, the death rate among Solingen grinders in 1905/06 was less than a third of that in Sheffield! Far-reaching improvements in occupational safety could therefore actually be achieved with relatively simple technical means. However, their general introduction only took place under government pressure. For a long time, the state supervision that remained in the mining industry from the time of the Bergregal did little to improve safety, as there was a close social connection between mining authorities and colliery administrations. Only the major strike of 1905 and the catastrophe at Radbod colliery (1908) brought about a certain change.

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The German mining industry only compared favorably with the USA, but not with Europe.[199]

When "Made in Germany" became a seal of quality towards the end of the 19th century, efforts were made to emphasize safety features as a special quality of German technology. Bismarck's accident insurance, which had initially met with resistance in German industry, now became a component of advertising abroad. It brought a competitive advantage on the domestic market over the American machine industry, which now had to "take into account some of the wishes of German customers for accident prevention measures". At the 1893 World's Fair in Chicago, the German department emphasized the safety of German railroads in contrast to the American railroads and the achievements of the Royal Technical Research Institute in Charlottenburg in materials testing. Accident prevention, however, where the big agriculturalists were in charge, was given a "disparaging verdict" (Wolfhard Weber) by the President of the Reich Insurance Office.

These two focal points of the presentation of German safety - railroads and materials testing - were typical and had their reasons. It was also significant that the safety motif was primarily played off against the USA, whose competition had threatened German mechanical engineering since the 1990s. The "proverbial contempt for human life" by the "Yankees" was already mentioned in connection with the World's Fair in Philadelphia, but even then it was criticized as a partially misleading prejudice. An essay published in 1913, *The Waste of Human Life in the United States,* defended the thesis that "nowhere in the whole civilized world has the waste of human life assumed such surprisingly large proportions" as in the USA and that the blood toll of technology there even exceeded the terrible number of executions in Russia.

"to insignificance". At the top of the list were the horror figures for American railroad casualties; the author calculated that the risk of death for American railroad employees was almost four times as high as that of German employees, and the risk of injury about 18 times as high! The criticism here was undoubtedly justified; the extreme contrast between Germany and the USA spoke for the benefits of state control of technical safety. Of course, German engineers and industrialists were reluctant to draw conclusions of this kind.[200]

The contrast between American and European attitudes to railroad risk was noticed and commented on from the very beginning. In 1854, Max Maria von Weber explained that in a region such as the American West, where conditions were uncertain anyway and large areas were characterized by

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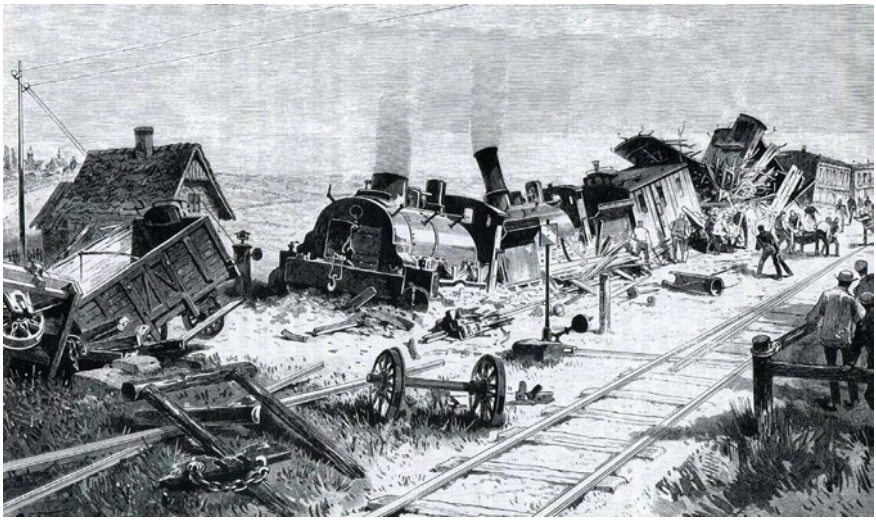

Figure 23: Serious rail accident on the Munich-Ingolstadt line, which was still single-track at the time, on July 7, 1889, in which ten people were killed. An express train had collided with parked wagons due to an incorrectly set points. From the perspective of the time that followed, it was a scandal to leave a main line with increasing train traffic on a single track. For four-year-old Max Weber, the sight of a derailed train near Verviers in Belgium in 1868 became a lasting memory: "The shocking thing for me was not everything that happened, but the sight of a being as sublime to a child as a locomotive, lying in the grave like a drunkard - the first experience of the transience of the great and beautiful of this earth."

The risk of the railroad was understandably hardly taken into account in the first place, whereas in already well-ordered societies, where "risk [...] was reduced to a minimum in all living conditions", the situation was quite different.[201] 19th century German society did not yet see itself as a "risk society" and was not prepared to engage in a game of "chance and risk" when it came to new technologies. From today's perspective, however, the American approach to technical risk only gave a foretaste of the indifference with which a German society gripped by automobilism in the 20th century accepted thousands and tens of thousands of traffic fatalities a year.

The Germans enjoyed an early reputation for safety, not only with the American railroads, but also with the British railroads, although this was not always justified. In Germany, it was already possible to draw on English experience; state control was stricter from the outset and competition for speed between different railroad companies was less pronounced. As early as 1846, German railroads were already

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In 1847, an association of German railroad administrations was founded; a meeting of engineers convened by this association in Berlin in 1850 agreed on safety regulations for the whole of Germany. At the beginning of German railroad history, there were no *old happy-go-lucky days* in which even an engineer of Brunel's caliber declared that, as an engine driver, if he encountered a locomotive on the same track, he would simply give it full steam ahead in order to push the opposing locomotive in front of him with his own momentum. As a result, countless level crossings were built in Germany with the expansion of the railroad network, more than in England. The "first major accident" on German railroads with 39 fatalities occurred in 1883 in Berlin-Steglitz when a warriors' club pushed through a closed barrier. As late as 1937, five times more people died at level crossings in Germany than in England. However, accidents of this kind were the fault of the people involved. In 1889, the German railroad accident statistics recorded that 48 people died through no fault of their own, while 554 died through their own fault.[202]

A central safety innovation such as the automatic brake was also highly attractive from a business point of view, as it saved the wages of the many brakemen who had to stand on every wagon of the long freight trains. A decisive breakthrough came in the 1980s with the American Westinghouse "fast brake". In contrast, the introduction of electric lighting made only slow progress on the German railroads. Gas lighting was still widespread after 1920, and safety precautions were aimed at making it easier for passengers to escape in the event of a fire by means of large windows, rather than eliminating the cause of the fire risk. In 1924, State Secretary Karl Helfferich, the German Nationalists' greatest political hope, was burned to death in a railroad collision in Bellin- zona: the accident provided the final impetus for the introduction of electric lighting. Up to that time, the possibilities of electricity in signaling had been insufficiently exploited in Germany. In this context, one author speaks of the railroad's "hostility to electricity, which is in its blood as a daughter of steam". In 1907, attempts began to bring locomotives to a standstill electrically from the outside; but it was not until the 1930s that the "Indusi" (inductive train protection) was introduced.[203]

The goal of further increasing the speed was set by the
German railroads at the end of the 19th century. In other transport sectors, too, it became apparent that the urge to increase speed was not particularly typical of Germany at the time. In aviation, Count Zeppelin became a national cult figure with his steerable airship, which impressed with its calmness, while Germany's enthusiasm for the motorized airplane was not typical of Germany.

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aircraft lagged far behind France and Italy. The Germans did not take part in the sensational race of the "clippers" on the world's oceans: the ocean-going sailing ships with their sharp keels, trimmed for speed. In the German-British arms race in naval construction, Admiral Tirpitz placed remarkably little value on speed. After the "Titanic" disaster of 1912, the German side noted with satisfaction that the German shipping companies had not participated in the international speed records for years. Around 1900, however, the German high-speed steamers had set their ambitions on surpassing the English ships in terms of speed, while the White Star Line, which built the "Titanic", held back.[204] Half a century later, in his textbook on nuclear reactors, the experienced power plant engineer Friedrich Münzinger still remembered the former battle for the "blue ribbon", the speed record for Atlantic crossings, as an example of speed nonsense.

Towards the end of the 19th century, one of the most important assets of technical safety in Germany was *materials research,* including the development of scientific materials testing methods. This was one of the central and most difficult problem areas of safety research, the importance of which was only just beginning to be recognized in the 19th century, when work was still mostly carried out with well-known materials, and which experienced a considerable revaluation in the 20th century. Materials research was a sector where technical safety and technical progress overlapped more than elsewhere and where powerful German industrial interests played a role: in particular the interest in proving the full value of German Bessemer steel for railroad tracks or German metallurgical cement for the construction industry, and the striving for standardization at national level, which came to fruition during the First World War.

Initially, the initiative lay with the customer: In the seventies, August Wöhler, a man from the railroad administration, was the pioneer in the scientificization of materials testing and the introduction of quantitative measurement methods. At the time when Reuleaux was issuing his "cheap-and-bad" verdict on German industry, he defended the view that only state control could guarantee good steel quality in the face of harsh criticism from the steelworks. In fact, the trend in material testing was towards state control, unlike in the definition and practical application of safety standards and - importantly! - the corresponding measuring techniques.

The new safety mindset, which focused on material qualities, served the industry and the VDI as a strategy to overthrow the previously dominant position of state construction officials in steam boiler supervision in Germany.

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questioning and restricting this. If "steel" was no longer something fixed per se, but rather something to be tested for its quality, then it no longer made sense to define the safety of steam boilers by a fixed ratio between pressure and wall thickness; and where no fixed rules applied, the matter was increasingly regarded as a matter for the officials to decide and became one for the technical experts.[205] Since the Industrial Code of 1869, the *state of the art* - the form was not encountered until after 1900 - was the benchmark for the official requirements to be imposed on industrial companies in the interests of environmental protection. However, the faster technology changed, the more the determination of its respective "state of the art" became a matter for experts, and technicians had to develop a consensus procedure together with entrepreneurs and trade supervisory authorities in order to be able to define a fixed "state of the art" in the face of change. This was one of the motives behind the development of corporate structures in German industry. Neither standards nor emission limits could be deduced from science. "At best, 'science' can provide a corridor within which the limit values, which also take economic aspects into account, are negotiated." The legitimizing value of the negotiated regulations was "incomparably greater" than the practical benefits (Peter Lundgreen).

As Max Eyth describes, safety standards were being developed elsewhere at the time.

The construction of the railroad bridge over the Firth of Tay, the central section of which collapsed on a stormy night in December 1879, taking a train with it, was a case in point. According to Eyth, the chief designer had needed the order for the large bridge in order to finally be able to marry his bride. To ensure that the cost estimate was not too high for the client, the safety dimensions of the bridge had to be kept within limits. At the time, it was impossible to calculate safety with mathematical precision. The unfortunate man confessed to Eyth: "If I calculated in such a way that the site manager found it acceptable, I could reach out for my bride. God forgive us both. She kissed me into a low coefficient of safety." Compared to this type of consensus-building, German corporatism did have certain advantages.

The increasing shift of supervision to the Dampfkesselüberwachungsvereine (DÜV), the forerunners of the Technischen Überwachungsvereine (TÜV), had a similar effect to that of accident insurance in counteracting the expansion of state industrial inspection. In 1900, the DÜV, which had become "dear to all industrialists", gained the official monopoly on the inspection of steam boilers, and in 1909 also of automobiles. In the following years, a push by the Reichspost for official monitoring of electrical engineering

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successfully fended off. The fearful concerns that the Reichspostverwaltung (Imperial Postal Administration) had harbored in 1891 about the safety of the surrounding area in connection with the power line from Lauffen to Frankfurt became an anecdote to ridicule official control and the fear of unpredictable risks of new technology. In the chemical industry, self-regulation by the emerging large companies became commonplace in the 1990s.[206] The questionable learning process, which had led to the view that safety was the sole responsibility of the experts and was best guaranteed by the collective self-regulation of the industry, had its effect. From today's perspective, one significant consequence of this development is that no law of technical safety developed as a uniformly structured area and no generally recognized safety standards.[207]

Towards the end of the century, electricity in particular gave rise to a new popular belief in technical progress and in the ability of technology to solve the problems it created in the long term. After all, it was clean and, at least in the home, noiseless; it did away with steam boilers and dangerous transmission belts in factories and sooty and foul-smelling gas lights in homes. It made it possible to use free and regenerative water power on a large scale. Especially in its early days, "electricity" was associated more with water power than with coal. The first railroads had already triggered an enthusiasm for technology, but at that time industrial technology was still limited to narrow sectors. It was only with electricity that the omnipresence of technology, the mechanization of life as a whole and the reconciliation of technology and culture became conceivable. With Max Weber, one can recognize here a technical-historical background to the breakthrough of modern art and the typical awareness of modernity at the turn of the century. At that time, there was even the possibility that technological progress could lead to a new social consensus, as the spokespeople of the German labor movement were now also convinced advocates of this idea of progress, even more enthusiastically than many members of the middle classes.

Marx was already in 1850, when electrification was still a surreal addition. The sight of an electric toy train in a shop window on Regent's Street in London had set him "on fire" and strengthened his conviction that the end of this revolutionary development of the productive forces would inevitably be the political revolution. He had even infected Wilhelm Liebknecht with his childlike enthusiasm. Even more than bourgeois ideologies, Marxism needed the idea of the momentum of technical progress and the distinction between concrete contemporary technology, which served to enslave workers, and abstract technical development.

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The assumption was that technological progress would overtake the purposes intended by capital with technology. The belief in a growing unity of technology and science was particularly popular among socialist theorists: the "spiritualization" of technology promised to banish the atmosphere of brute force from the world of work and restore the unity of manual and mental labour.

Such confidence was in no way in keeping with the mentality of the early industrial workforce, which viewed mechanization with suspicion and hostility. It is possible to identify a type of workers' association in the 19th century that can be seen not only as an imperfect forerunner of the later trade unions, but also as a social movement of its own kind: the trade associations, which were still characterized by "craftsmen-workers" and by no means rejected technical innovations per se, but were nevertheless opposed to a type of mechanization that devalued skilled manual work.[208] They were overtaken by the industrial trade unions at the end of the 19th century. The belief in progress of this new type of trade union had affinities with the bourgeois idea of progress and reflected the confidence of new working-class elites that the increase in productivity and need for qualifications brought about by technical progress would benefit themselves; after all, an upper class of skilled workers generally set the tone in the industrial trade unions as well.[209]

"Every new machine preaches the gospel of social emancipation," triumphed Wilhelm Liebknecht. For the sake of technological progress, the Social Democrats in the Reichstag voted for imperialist and militarily motivated bills such as the steamship subsidy and the Kiel Canal under the Socialist Law. "The conquest of the air is the symbol of victory over the opposing forces of nature, the promise of the final victory of reason", enthused the *Berliner Volksblatt* in 1909 at the sight of the Zeppelin. Bebel's widely read bestseller *Die Frau und der Sozialismus (Woman and Socialism)* contains a devout enthusiasm for technological progress that is not often found in such unrestrained form, even in the bourgeois technological literature to which Bebel referred. First and foremost, the belief in the "revolutionary effect" of electricity, "this most powerful of all natural forces"; Bebel assumes that there are already accumulators to store "large amounts of power" for "any length of time", and he sees not only electric traction engines of 260 or even 300 kilometers per hour, but also an "electrification of the entire shipbuilding industry" within reach. "A few square miles in North Africa" would supply the entire German Reich with solar energy. Even "the greatest problem of chemistry, the production of food by chemical means", had "in principle [...] already been solved"; the time would come when man would feed on chemicals that were "more perfect".

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than the natural substances, and where perhaps "the deserts would become the favorite abode of men", "because it would be healthier there than on [...] the swampy rotten plains where agriculture is now practiced" - Bebel approvingly quotes a speech given at a banquet of the syndicate of chemical manufacturers by the French chemist and several-time minister Berthelot.

For Bebel, occupational safety was also simply a question of applying existing scientific knowledge and technical achievements. In a Reichstag debate on industrial inspection (1891), he expressed his conviction that "today, technology and science have already reached such a level that 90 percent of all industrial diseases and accidents would become impossible" if only the money were made available for the practical use of these advances. In typical cases, it was the employers who, in order to ward off costly regulations and accusations of negligence, questioned this optimism and insisted that it would "always remain the case that certain trades and professions entail dangers".[210]

Social democrats were well aware that industrial development not only led to the centralization of production and more complex technology, but also to the emergence of home-based work. But in the eyes of the German socialists, this cottage industry was the epitome of the historically outdated and detestable: a health-destroying, unrestrictedly exploitable industry that was removed from trade union organization.
"Dirty competition" for the class-conscious factory workers. Even a visionary like Lily Braun expressed downright disgust at cottage industry and wished it no social protection, but only its downfall. She expressed the hope that, despite the complaints of nature lovers, the railroad and factory closures would penetrate the remotest mountain regions in order to put an end to cottage industry in its last corner. According to the prevailing conviction in social democracy at the time, the skilled trades as a whole were doomed, and in the 1990s the Social Democrats were the only parliamentary group in the Reichstag to refuse to take any protective measures for the skilled trades and did not even pay the usual lip service to saving the skilled trades through small engines.[211]

Did the German labor movement's official faith in technology reflect the general trend of the time? After all, it contrasted with the position of the English trade union movement, which took over the basic feeling from the old trade associations that mechanization was something to be suspiciously controlled. In this way, the introduction of American methods in English mechanical engineering was permanently inhibited. The belief in technical progress was not originally an integral part of the demo

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It was more the case that the idea of progress was technicized towards the end of the 19th century at the expense of its traditional political content.

In the Wilhelmine era, when the Kaiser himself was a technology enthusiast, there was already a belief in technical progress that was detached from the old political concept of progress. "It is very strange that the aristocratic boys are so passionate about technology," noted Baroness Spitzemberg in her diary on December 19, 1913. Starting with Bismarck's grandson, they "dreamed day and night of hunting, horses and dogs like previous generations".[212] Indeed, technology opened up new territory for hunting fever. During the First World War and for a long time afterwards, children learned the catchy musical tune: "When Hindenburg was still small and lying in his cradle/Then his mother kissed him, but his father said: 'Hindenburg, you'll get a zeppelin; Hindenburg, you'll get a flying machine; Hindenburg, you'll get a car/With that we'll go, we'll go to St. Petersburg!"

Just at the time when the belief in technological progress was firmly established in the ideology of the German labor movement, a development began to emerge in the workplace that was likely to shake the faith of those affected. In retrospect, the 19th century in the iron and machine industry soon seemed like a cosy time; the era of rationalization surges began, traditional specialist qualifications were called into question and increasing pressure was exerted on the pace of production, creating new sources of accidents and turning nervousness into a mass phenomenon. Levenstein's impressively documented study on the "joy of work", grudgingly praised by Max Weber, is full of harrowing testimonies of joylessness, monotony and exhaustion even in the metal industry, where manual working methods persisted for a long time.[213] Rosa Luxemburg recognized the political dilemma that arose if one assumed, as she did, that the path to the collective emancipation of the working class led via technical progress: for the current interest in concrete technical improvements lay with the capitalist, and "every technical revolution", according to her, worsened the "immediate situation" of the workers directly affected, in that their work "more intense, more monotonous, more agonizing".[214] The psychological stress of work, which has become increasingly noticeable since the end of the 19th century, is a problem that has remained without a radical solution to this day, because this is where it was most difficult to prove causalities in a watertight manner, and where there were no simple technical methods of remedy, but where the social system of production came into focus.

Overall, the technological euphoria at the turn of the century was by no means unbroken.

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The development was accompanied by rampant unease and pessimistic sentiments. However, these could hardly be mobilized as a counter or braking force to technological development. Increasingly, the criticism led to a resigned cultural pessimism of a kind that ultimately encouraged Germany's striving for world power and thus drove forward a development that swept away all barriers against technical innovations that were necessary in terms of power politics.

From around 1880, the view that we were living in a "nervous age" and that modern nervousness stemmed from the accelerated pace and sensory overload spread almost overnight. This horror is important as the mental basis of social policy and the school and life reform movement; however, it led to natural healing centers rather than to a reorientation of technology. The nature conservation movement that emerged at the turn of the century also contributed to the fact that the unease about technology was relegated to reserves where it no longer clashed with industry in general.[215] Thus, that period has its deep ambivalence: as the first great period of "hygiene" policy - and "hygiene" was used to describe much of what was then known a century later as the "hygiene" movement.
"environment" - but at the same time as a heyday of pseudo-solutions, in which the containment, superficial elimination, relocation and invisibilization of many problems caused some remaining inhibitions against unrestricted technical progress to disappear. Perhaps something similar to the
"environmental movement" would have emerged after 1970 if the era of the world wars had not set completely different priorities.

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IV. Wartime, pre-war and post-war times: The rationality of mass production, power and need

1. From the turn of the century to the 1950s: a cycle in the mechanization of all areas of life

It was not without reason that the New Year's Eve of 1900 was accompanied by the feeling that a new era was dawning. In the midst of the history of the German Empire, between 1890 and 1910, a horizon crossing towards a new awareness of modernity can be recognized, which is initially difficult to deduce from the social conditions, where the impression of rigidity predominates, while it emerges all the more strikingly in the development of art and architecture, taste and design. This atmospheric shift is most likely to find a concrete reason in the history of technology, production methods and company organization. The machine hall built by Kirdorf at the Zollern 2/4 colliery in Dortmund-Bövinghausen (1902) was not only the most important monument to Art Nouveau in the Ruhr industry, but also contained the world's first electric hoisting machine. The hall of the AEG turbine factory in Berlin (1909) designed by Peter Behrens, a pioneering work of modern industrial architecture, heralded the victory of the steam turbine over the steam engine. Both refer to an intersection of architecture and the history of technology at the beginning of the new century. Just as the cultural modernism that was later associated with the 1920s had already taken shape in the decade before 1914, much of what was considered "new technology" after 1918 and was attributed partly to the war and partly to the USA also had its origins in that period.[1]

Against the backdrop of the history of the empire, however, all of this appears only confusing as long as one equates this kind of modernity with social and democratic progress and an increase in rationality. From a distance, however, it becomes clearer that the modern style that was breaking through at the time was not as social or as functional as it pretended to be. In his programmatic essay on the founding of the Deutscher Werkbund (1907), Friedrich Naumann placed it alongside the "efforts to popularize the idea of the German fleet".

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The one and the other are "an expression of the turn of the German spirit towards the world economy and world politics", including the Werkbund; because the conquest of the world market in the arts and crafts requires "original achievement, German style, which asserts itself in the rest of the world". The "almost volcanic uprising of an upper class of industrial artists", which was currently giving industrial products their own new form and elevating "industrial art to a national issue", was a movement of "master craftsmen among artists". The comparison of the Werkbund with the navy had the specific meaning that the Werkbund wanted to create a modern, technical and at the same time specifically German style of design, not least with a view to export. At one time, the founding convention of the Werkbund was to be held in St. Catherine's Church in Nuremberg, alluding to Wagner's "Meistersinger" and the old glory of craftsmanship, and the Deutscher Werkbund repeatedly sought an alliance with the crafts. However, this alliance never lasted, and in the end this pioneer of modern design was "universally regarded as the enemy of craftsmanship".[2]

Modern design contained an element of elitism and a thirst for recognition, as did modern technology. In 1910, Otto Kammerer, a mechanical engineering teacher at the TH Berlin, made the somewhat premature prophecy before the Verein für Socialpolitik that the development in mechanical engineering would "not, as is often assumed, lead to more and more manual workers being placed in the service of the machine", but on the contrary, that "the manual workers would be increasingly eliminated" and "a small number of high-quality workers" would take their place. On the part of engineers around 1900, elitist changes were partly a reflection of the fear of a "mobbing of technology" (Georg Siemens) and a relegation of engineers to the mass and routine operations of rationalized large-scale industry.[3]

Wilhelmine naval armament, which was popularized with the first modern advertising campaign of German politics, made war technology the driving force behind technical innovations in the steel industry on an unprecedented scale. A steel integration of vehicle and weapon, of steam and powder power on such a scale had never been seen before, and neither had a technical arms race of this kind, which forced a constant and systematic effort to increase the quality of steel. From then on, it was possible to imagine that armaments were the driving force behind technical progress, even if this belief did not become an obsession in the Wilhelmine era to the same extent as it did in the 1960s, when the arms race extended to outer space. The construction of warships was technically more attractive than all the major contracts that the land army had to offer.[4] The naval mania demonstrated to an unprecedented extent how a combination of industrial interest, technical expertise and the desire to build ships could be realized.

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nik fascination and systematic opinion-making were able to steer armaments in directions that were irrational even from a military point of view, as the fleet did more harm than good to the empire in an emergency: this is another aspect that underlines the period around 1900 as a caesura in the history of technology.

August Thyssen, the pioneer of new-style *economies of scale* among the Ruhr magnates at the beginning of the century, justified the need for new rationalization pushes in 1902 with the warning: "German industry cannot permanently bear the burdens of the expensive railroad monopoly, the coal and coke syndicate, the pig iron, semi-finished and finished products (syndicates)." The
The "new technology" after 1900 had the basic feature in common that it shook the dominance of coal and steel, of steam engines and steam locomotives: through gasoline and oil, through light metals and plastics, through electric power and gasoline engines. This change resulted in new regional profiles; the most important concentration of the automotive industry was in the Stuttgart area, far from sources of raw materials and sales centers, but in the midst of a population of workers and craftsmen accustomed to precision mechanics.

In the early 20th century, we can also speak of a new generation of technology with regard to the "productive power of man". The "high-speed steel" that emerged after 1900, with its greater hardness, was used to increase the speed of production; the carbide made of tungsten, titanium and tantalum carbide developed by German engineers in the 1920s enabled the cutting speed of machine tools to be multiplied again compared to high-speed steel. Schlesinger demanded that fits of thousandths of a millimeter should be observed in machine tool construction: This was where the "intuition" of the most experienced specialists failed - no wonder that "fits" were the most controversial topic in the machine shops of the time. Iron and steel had been machined using manual methods; the new hard and light metals were foreign to the trade. This does not mean that experience was completely replaced by theory when it came to new materials: here, too, it was important to develop a "feel" for the material over time.[5]

In electrical engineering, the electric motor, wireless telegraphy and radio brought a generation break. The electric motor required an integration of electrical engineering and mechanical engineering, and light metals required cooperation between the electrical and metal industries. Wireless telegraphy, which made cable laying - the great feat of early electrical engineering - superfluous, received significant initial impetus from the military and navy, but subsequently also from an army of amateurs, while the physicist Hertz, the discoverer of electromagnetic waves, who died young, had little idea of the technical consequences of his discovery. High-pressure synthesis required

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a type of chemist like Carl Bosch, who was able to cooperate with heavy industry and large-scale mechanical engineering. The new generation of technology is characterized not only by specific individual technologies, but also by networking and cross-connections and by integration into organization and "systems". Only now did the abstract term *"technology"* become a standing concept in general usage.

"Technology" also became one of *Max Weber's* major themes at the time. The CD-Rom of Weber's works reveals what the Max Weber industry to date has no idea of: that "technology" and "technical" appear no less than 1,145 times even in this incomplete edition of his works, and often in a way that is not at all banal. In places, Weber, who was living in Berlin-Charlottenburg at the sight of the nocturnal world of lights of the then leading "electropolis" of the world, literally fell into a technological determinism, especially with regard to modern "artistic culture": According to Weber at the first German Sociologists' Conference in 1910, this could only be "born through the existence of the modern metropolis", "the modern metropolis with streetcars, with subway railroads, with electric and other lanterns [...] and all the wild dance of sound and color impressions, the impressions acting on the sexual fantasy and the experiences of variations of the mental constitution, which work towards the hungry brooding over all kinds of seemingly inexhaustible possibilities of living and happiness." The modern city as an optical phenomenon: this is "a point at which technology purely as such has a very far-reaching significance for artistic culture".

The new technology itself became an inseparable part of political systems. National Socialism, whose special trait consisted more in its style of action and its way of staging itself than in its interests and ideas, would have been unimaginable without loudspeakers and radio, without airplanes and searchlights. While in the 19th century, technological progress was often ascribed a democratic effect, in the early 20th century it became clearer than ever that technology was not only capable of strengthening the dominion over nature, but also over people. Johan Hendrik Jacob van der Pot, the author of the most comprehensive survey to date on the "evaluation of technological progress", recalls that he became aware of the significance and ambivalence of modern technology when, as a concentration camp inmate, he experienced how "a small guard team with machine guns and electric barbed wire could keep many thousands of concentration camp inmates in check".[6]

Around 1900, *"speed"* was a particularly exciting sign of the new era. The American philosopher of history Henry Adams, who recognized a "law of acceleration" in the entire history of the world at the time, found an explanation for this outside of

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The new energy could be felt everywhere; the Rhine had become more modern than the Hudson; Cologne Cathedral seemed as absent-minded next to the main railway station as Chicago Cathedral. In 1899, in a lecture on the subject of "high-speed railways", Riedler called "the increase in operating speed" "the constant goal of technical progress", which "always leads to new perfections". In a secular article at the turn of the century, the engineer Wilhelm Berdrow, later Krupp's in-house historian, proclaimed that "increased speed in all technical operations" would be "one of the main
be the 20th century".

Figure 24: Title of the programmatic book Schnellbetrieb by Alois Riedler, the most prominent German mechanical engineering teacher of the time, published at the turn of the century. Note how the illustrator - clearly inspired by Art Nouveau - interprets Riedler's Schnellbe- trieb: Around the title, a circle of hares jumping over snails. Below them, a childlike, naked cyclist standing on the pedals with a gloriole like a young god, his hand stretched out towards the eagle above him, which holds a bundle of lightning bolts in its claws: A symbol of electricity, of "tamed lightning". The bicycle is still the embodiment of the new speed! In the foreground, the bearded worker of old scratches his ear in amazement.

At that time, the word "tempo" took on a new meaning.
Since then, "in a reasonable amount of time" has meant: "high speed" - this was the "reasonable amount of time" for the new speed frenzy generated first by the bicycle and then by the automobile. Since the turn of the century, the obsession with records has spread in sport, and in dance "the American slide dances inspired by jazz": at that time, an unusually striking connection emerged between the history of industry and technology and the motor skills of the body.

This was no mere fad, but an epochal turning point in the history of mentality, production methods and work. It is reflected in the rapidly increasing nervousness around 1900, which had been regarded as an "American disease" until the 1880s. From the

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Inmates of the Berlin State Insurance Sanatorium Beelitz existed in 1897
18 percent, in 1904 40 percent were "neurasthenics". From then on, special attention was paid to shortening transport routes and intensifying work in large-scale reorganizations.[7]

The Zeiss company, whose reputation was based on the highest precision work, switched to the eight-hour day in 1900. When company owner Ernst Abbe asserted at the German Mechanics' Conference in 1901 that the reduction in working hours had led to an increase in performance and strongly advocated the general introduction of the eight-hour day, he was met with disbelief and fierce opposition. In the period that followed, increases in the pace of production - the "Bosch pace" became a standing term! - led to strikes without compensation for working hours and wages. Over the decades, however, a new social consensus emerged on the basis that the intensification of work and increase in working hours were coupled with reductions in working hours and wage increases. Under these conditions, workers gradually became accustomed to the faster pace and greater continuity of work, especially as the memory of the quasi-manual autonomy of dealing with time was lost.

When electrification in Solingen meant that some of the grinding work became home work again, as in the old days, the new home workers had internalized the industrial time economy. Whereas the old semi-autonomous grinders had been proud to be able to "take a break" at will, one post-war grinder believed that home workers had "always strived to work as rationally and time-savingly as possible"; everything now revolved around speed. For the majority of workers, especially the unskilled, it became a matter of course that satisfaction was not sought in work, but in leisure time and the leisure activities made possible by higher wages. All the more reason why the *"joy of work"* became a central and characteristic theme of German industrial sociology.[8]

Roughly speaking, we can recognize a cycle in the social history of work and the relationship between man and technology. From the turn of the century until the global economic crisis, the vocabulary of "rationalization" and its
"Schnell-" and "Fließ"-compositae had its effect. In contrast, the period from the 1930s to the 1950s appears - also due to the war and reconstruction - as a time of continuation and modification of existing rationalization approaches, whereby some negative experiences from the early days of flow work were evaluated and production was adapted to the strongly changing requirements. It can be assumed that under these conditions new niches of relative autonomy were created.

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Figure 25: Telephone operators in a telephone exchange in the early 20th century, when telephone connections still had to be plugged in by hand. A "lady from the exchange" was responsible for 10,000 connections ("jacks"). Among the new professions at the time, this was considered to be the one with the worst nervous strain; neurologists believed that all telephone operators would sooner or later become hysterical or neurasthenic. In 1902, all the staff at a new telephone exchange opened by Siemens in Berlin burst into fits of crying when they were inundated with impatient calls and could no longer keep up with the calls. The profession quickly became a woman's job, as it was believed that only women could maintain a friendly voice under such stress.

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This also contributed to a more relaxed situation in the factories compared to the previous period, which benefited both the National Socialist regime and the CDU government.[9]

Around the turn of the century, Karl Bücher, one of the heads of the historical school of economics, wrote the classic *work* on the old joy of work in *"Arbeit und Rhythmus" (Work and Rhythm)* - a collection of rhythmic work songs. He lamented the fact that the introduction of rotating machines, which went hand in hand with the growing pace of the economy, was destroying the rhythmic nature of work - which was often still present in older machines - and thus one of the main sources of the joy of work. That's how descriptive, even cozy, economics was back then! In 1910, Bücher described the trend towards mass production as a "general law of the capitalist enterprise", which, as he wrote, had illuminated many phenomena that had previously been treated in isolation "as if with a flashlight and placed them in a larger context". The law was based on the premise that technical progress increases the fixed costs of companies in stages.

Indeed, in the period from the turn of the century to the 1950s, *economies of scale* based on technical and organizational integration and mechanized and standardized mass production came to full fruition in Germany. In the end, the decades-long dream of the Volkswagen came true; after phases of misery and hopelessness, a level of mass prosperity was achieved that had previously only been imaginable in the USA. The history of everyday life in Germany, with the historically unprecedented succession of "collapse" and "economic miracle", of hunger and "feeding frenzy", made the fairy tale of the land of milk and honey come true, albeit with a lot of hard work.

At the time, mass production seemed like the logical condition for mass prosperity. But it was only true to this extent in a certain historical situation, when there was a huge backlog and new demand for products that could be mass-produced. A permanent dominance of this mode of production is only conceivable in a throwaway society that ignores the ecological problems of disposal. The German history of the
20th century sheds light on the historicity of mass production.

Until the beginning of the 20th century, there were different opinions as to whether Germany should be considered a resource-rich or resource-poor country: Measured in terms of coal and iron (when using the Lorraine minette), the German Empire had a resource-related locational advantage that shaped the profile of German technology. With the growing importance of oil and light and non-ferrous metals and the loss of Lorraine, Germany became a country with few resources. In terms of wages, too, the

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German industry no longer had the cost advantage over Western European competitors that had been a decisive factor in export and thus also technical development until the late 19th century.

Even more than before, it now became the prevailing doctrine that the future of German exports lay in particularly refined products based on highly developed technology and/or skilled labor. In 1938, the share of raw materials and agricultural products in German exports had fallen from 29.2 to 13.4 percent compared to 1913, while the share of machinery, transportation equipment and chemicals had risen from 19.9 to 40.8 percent.[10] Statistically speaking, it was only now that chemicals could be considered a leading German industry. The "chemistry of scarcity", which extracts natural substances through synthesis, was contrasted with the - scientifically inferior - "chemistry of abundance" of the colonial powers and the USA as the salvation of a country with few resources.[11]

The Americanization thrusts, which reached their first peak in the 1920s, were more in tension with technological nationalism than ever before and since. A scholar of Sombart's stature castigated "Americanism" as a "national disease like plague, cholera, leprosy", to which the Germans were particularly susceptible. Never was so much of
"German technology" as in the time of the wars and the National Socialist autarky economy. However, such considerations were regularly caught up in the maelstrom of power and armaments policy; concepts for a consistent adaptation of technology to German conditions and needs had no lasting chance. As large parts of German industry needed exports, self-sufficiency efforts were inevitably combined with contrary tendencies; it was precisely this hybrid combination of autarky and expansionism that gave rise to the National Socialist "Großraum" policy.

Even during the Nazi era, the American model had by no means lost its appeal. Fritz Todt, the highest-ranking technician of the "Third Reich", saw his role models in Taylor and Ford; Hitler himself was fascinated by American technology and internally dismissed the claim that "German factory work" could not be replaced by any machine as a "bluff". While there was a lot of talk about the assembly line in the 1920s, the practice of "assembly line work" was generally still faltering, the automatic assembly line became more widespread during the Nazi era, for example in the automotive and laundry industries. Only now were skilled workers replaced by semi-skilled workers on a larger scale in the automotive industry.[12]

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Trink
Coca-Cola
Köstlich und
Das Warenzeichen „Coca-Cola" ist das allbekannte Kennzeichen für das einzigartige Erzeugnis der Coca-Cola G.m.b.H.
„–und das ist für mich"

Figure 26: Coca-Cola advertising poster from 1938. Although Coca-Cola became the epitome of the modern American style of consumption, sales were also able to expand unchecked in Nazi Germany: From 1934 to 1939, the Coca-Cola company increased the number of its German bottling plants tenfold, from five to 50. The only concession to contemporary Germanism: that German Santa Claus advertised the American drink. However: Coca Cola is for him, not for the children!

In most areas where technology had still reached its limits in the 19th century, the first half of the 20th century opened up prospects of seemingly unlimited mechanization: in mining and construction, in agriculture and food processing, in the household and in the office.

Although coal had become the key sector for economic growth in the middle of the 19th century, the German coal mines

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Until the beginning of the 20th century, there was a conspicuous reluctance to mechanize the work of the miners: a sign of the great importance attached to not disrupting the functioning of the informal social system that had become established underground and was able to train and integrate the flow of new, mostly unskilled workers. Before 1914, German *mining* lagged behind not only the USA but also England in terms of the degree of mechanization; nevertheless, the shift output in the Ruhr was about as high as in English mining. Shortly after 1900, mechanization trials began underground; however, the shearing machines and shaking chutes developed in England and Belgium first had to be adapted to the geological conditions of the Ruhr. The new techniques initially led to many failures, which the miners registered with grim satisfaction.

Existing attempts at mechanization came to a standstill due to the First World War. The 1920s brought a breakthrough; at that time, the Ruhr was far ahead of the English mining industry in terms of mechanization. By 1925, the number of pneumatic hammers, which had been as high as 264 in 1913, had risen to around 50,000, although there was still passive resistance to this equipment among the miners, which made the already high level of health hazards of the work of the hewers even worse. For the old Sombart, the shearing machines were also an example of how technical progress was making work "inhuman"; in the Ruhr, they were not widely used in the 1920s for geological reasons. The new technology turned miners' work into an apprenticeship; training newcomers was no longer the sole responsibility of the underground "comradeships". The shaking chutes introduced conveyor belt-like transportation technology to the mining industry. The control of work was increased, but so was the cooperation between workers. As autonomy was reduced, the need for trade union organization increased. Only the full mechanization of coal mining, which was driven forward in the 1950s, eliminated the traditional working world of the miner.[13]

While the German construction sector was characterized by technical
While Prussia remained traditionalist in terms of architecture and art, Germany became a stronghold of the architectural avant-garde after the turn of the century. Here, more consistently than in Western Europe, the *combination of architecture and industry* and serial mass housing construction were elevated to a program, spurred on by the political upheaval of 1918, when in Prussia the provision of small apartments was declared by law to be the task of the state.[14] Whereas normal housing construction had previously been the domain of small and medium-sized construction companies, it now became a field for large-scale projects. The Frankfurt-based Philipp Holzmann AG, the largest German construction company

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which had specialized in large representative buildings and large-scale hydraulic, civil engineering and railroad construction projects (Kaiser Wilhelm Canal, Baghdad Railway) during the German Empire, switched its corporate strategy to social housing construction after 1918.

However, the industrial production of houses remained a mere program. Residential units were designed as series, but built by hand. In 1921/22, there was a sensational competition for the design of a huge residential tower block at Berlin's Friedrichstrasse station; the architects competed with ideas for a "German" building that contrasted with the American *sky-scrapers,* but these and other high-rise plans failed. The "cry for the tower house", which was put into the mouths of the masses looking for housing, came more from the throats of architects striving for a monumental effect. As Gropius complained in 1929, high-rise construction came up against the barriers of German building legislation. "Skyscraper" dimensions in the American style only reached German high-rises in the 1960s, and then only in a few places: signs of a new period of unleashed Americanization, in which the pitched roof, which corresponded to German weather conditions, was decried among architects as reactionary, although it was not possible to make many flat roofs - starting with the roof of the Bauhaus in Dessau - rainproof.[15] Backlash against this kind of modernism was not long in coming.

In the 19th century, *timber construction* was used by most German engineers.

only since the early 20th century has there been a growing trend towards "Timber engineering". Wood as a material suited the prefabrication of building elements; it was also appreciated by some pioneers of modern construction because it offered attractive possibilities for an architecture that emphasized unclad building materials. After 1918, timber construction in Germany was in line with the slogan of building cheaply and with local raw materials. A decisive technical leap in the use of wood for large buildings was the gluing of wood, which was made possible by the new synthetic chemical resins; until then, glue had only been available to carpenters, but not to carpenters. Glued laminated timber construction made it possible to bridge large spans unsupported and still build light and elegant buildings; timber construction was now able to compete with the freedom of form of concrete. The experience of craftsmanship was surpassed by glulam construction; gluing could no longer be done "by feel". Gluing became the work of specialists and was subject to official supervision. Even the arrangement and dimensioning of the fasteners in engineered timber construction could only be "left to the executor in exceptional cases".[16]

Chipboard was the first artificial wood-based material available.

tion. Plywood, which was produced in the second half of the 19th century from the

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The chipboard, on the other hand, which allowed the use of previous wood waste, emerged as a German development during the period of the National Socialist policy of self-sufficiency, but only became more widely accepted in the 1950s, when the possibilities of highly mechanized mass production were used in its manufacture. The Federal Republic of Germany became the largest chipboard producer in the world.[17]

Technization of the office, of administration, i.e. an area that expanded particularly strongly in the 20th century: the connection between technical change and social structures took on a new dimension. In 1890, a census in the USA was successfully analyzed for the first time using Hollerith punch card machines. Austria quickly followed suit; in 1896, the Prussian State Statistical Office still considered the "human, thinking material" to be cheaper and more reliable than the Hollerith machine; but this changed by 1914. The "punch operator" became a new profession for women. The typewriter, which had been allowed in state chancelleries since 1897, also spread in the course of the "feminization" of the secretarial profession and seems to have promoted this trend.[18] Carbon copies and matrix copies multiplied the paperwork. The telephone did little to counteract this, but facilitated direct communication between the top and lower offices, bypassing the formal channels of authority and thus promoting centralized control. Schlieffen was inspired by the telephone and radio telegraph to create a completely new image of the chief strategist in a future war.[19] The telephone only became a general and permanent means of communication in Germany, even outside the service, in the 1950s.

Hugo Münsterberg (1863-1916), the German-American industrial psycho chologist, who embodied the combination of the American and German rationalization movements, said as early as 1912 that "scientific management" would "perhaps nowhere be as beneficial as in the kitchen and the utility rooms", where the effect "would be repeated millions of times over" and "the final sum of energy savings and emotional gain would be particularly considerable". The decline in service personnel in many middle-class households after the war increased interest in technology. *Technization and rationalization, even "scientification" of the household* became a popular topic in the twenties, whereby in this traditional realm of women, the concepts were even further ahead of reality than in industry. There were reasons for this; Marie-Elisabeth Lüders criticized in 1929 that the "concept of rationalization of domestic economy" was "far too narrowly defined". "Economic efficiency need not always be expressed in terms of numbers; relieving the housewife is just as important". In the kitchen, there was the ame-

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rican model and the English model for the bathroom; but in German households at the time, "rationalization" was more about economy than convenience.

In the concepts of the time, the mechanization of the household was primarily associated with electrification. Electricity opened up unlimited possibilities for mechanization in the private sphere for the first time, whereas until then mechanization plans, which required an artificial drive, were linked to collectivist ideas and their spread was inhibited by them. In the 1920s, a battle broke out between gas and electricity for the German kitchen. Some local authorities were initially uncomfortable with the expansion and low-price policy associated with the electrification of cooking. The Berlin city council temporarily banned Berliner Elektrizitätswerke from advertising electric stoves, and other cities followed suit. The *economies of scale* in the energy industry were still contested. Hydropower-rich countries such as Switzerland and Norway became "the creators of electric cooking in Europe". This does not mean that the German kitchen remained completely unchanged until the first half of the 20th century: there was also a variety of mechanization possibilities on a small scale and based on manual work. Until the 1950s, a "technical revolution" in the household was hindered by the frugal habit of using existing appliances for as long as possible.

Perhaps the most profound change in the everyday life of housewives was mechanization

the "big wash", the most laborious work. But the development of a washing machine that was affordable for the majority of households, which not only rotated at high speed but also cleaned cleanly and gently without the need for reworking, took a remarkably long time: a process that exemplifies the problems that arose when technicians, who had been entrenched in the male world, sought to appropriate a female sphere of experience.[20] Electric irons also had to overcome considerable childhood illnesses; gas irons were harmful to health.

The *mechanization of food production*, which was also closely linked to the social history of domestic work, did not get beyond the initial stages in 19th century Germany; this trend was more characteristic of Switzerland at the time, where one of the main routes to industrialization was the factory production of dairy products, i.e. cheese and chocolate. But from 1900 to 1914, the number of canning factories in Germany grew from 172 to 322, and their production weight increased from 35 to 80 million kilos in the period from 1907 to 1914 alone. The First World War accelerated the spread of canning, although it had already been proven at the time that the quality of food was better preserved when frozen than when heated. In 1900, the Bielefeld-based custard powder producer Oetker moved into its first factory building

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and used special machines powered by a gas engine for powder mixing. After 1890, the largest chocolate factory in Germany was built in Hamburg-Wandsbek with a "giant rolling mill", hydraulic presses and steam turbine drive. The mass production of chocolate and cigarettes brought the first wave of penny vending machines at the turn of the century. From 1896, German cities even gained a lead over the USA with "vending machine restaurants", although the sense of automatization was very doubtful here in particular. In the brewing industry, attempts to speed up the fermentation process began after 1900. The first newly invented and industrially produced mass foodstuff was margarine; here, German products were still far behind foreign qualities in the 1920s. But by 1933, German margarine production had risen to 90 percent of butter production - presumably not least as a result of the economic crisis. It was even more innovative in marketing than in technology: with the collectible pictures that were part of the childhood world of entire generations.

The First World War doubled the demand for cigars in Germany. From 1901, this characteristic stimulant of a fast-moving era was produced in mechanized mass production by Dresden-based Jasmatzi AG, following the American model. In Dresden, which had become the German cigarette city in the second half of the 19th century thanks to Russian and Greek emigrants - the mosque-like building of the Yenidze cigarette factory (1909) can still be seen today, which even shone in new splendor after the end of the GDR - around ten billion cigarettes were produced in 1925; this extreme level of uniform mass production made the industry extremely competitive and crisis-prone. The opposite extreme in terms of mechanization was the cigar, which was still produced manually, partly at home and partly in small rural businesses. The 1933 ban on machinery in the cigar industry - a unique historical phenomenon - preserved this situation until after the Second World War.[21]

The *mechanization of agriculture*, which in the age of the steam engine could hardly go beyond certain limits, also began to move significantly in the early 20th century. The petrol engine was groundbreaking, as was the fact that some armaments manufacturers sought to switch to agricultural machinery production after 1918. In 1920, a Reich Committee (from 1928 the Reich Board of Trustees) for Technology in Agriculture was founded; it devoted special attention to the development of agricultural machinery and tractors for small and medium-sized farms and, from 1928, also dealt with the adaptation of the American combine harvester to German conditions.

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These efforts were thwarted by the economic crisis; the German nationalist agricultural politician Schlange-Schöningen warned urgently against "agricultural Americanism" in 1930. "No fertilizer spreader spreads more evenly than the experienced farmer by hand; no self-binder [...] binds more carefully than the experienced farmer's wife." During the First World War and afterwards, when imports of Chile saltpetre dried up, German farmers had to switch to synthetically produced nitrogen fertilizer, which gave German chemistry a new "national" image. When the gunpowder industry switched to fertilizers after 1918, inexpensive chemical fertilizers were available as never before; but German agriculture also had its first experiences with harmful over-fertilization. By today's standards, the mechanization and chemicalization of farming in the interwar period still seems modest. At that time, individual innovations were mainly added to the traditional system of the farming economy. It was not until the 1950s that innovations began to add up to a new system that changed the face of agriculture beyond recognition.[22]

Last but not least, sexuality was also affected by the products of industrial technology. In 1912, the Breslau economist Julius Wolf published a book on the advancement of contraception entitled
"The rationalization of sexual life in our time" and demonstrated even before Max Weber what could be done with the rationalization concept. Thanks to advances in rubber processing for electric cables and bicycle tires, rubber condoms also became technically mature products after 1900. Initially they came from France and the USA, but they were soon also manufactured in the German Reich, despite calls from the right wing to ban contraceptives in the wake of the alarm about Germany's declining birth rate after the turn of the century. Condoms had the advantage that they could also be used as "hygiene articles". The condoms made from the appendix of sheep were the most comfortable, but they were too expensive for the lower classes; only the rubber condom could become a mass product. However, the social physician Alfred Grotjahn complained as late as 1914 that the use of the rubber condom was so unpleasant that it threatened to "discredit the use of the condom altogether". This product offered all the more opportunities for quality refinement by resourceful entrepreneurs such as Julius Fromm.

The "modernization of preventive technology" progressed inexorably.
The condom was one of the victors of the First World War. At the same time, the morally dubious utensil gained national sanctity for better or worse by preventing the German warriors on the Western front who escaped the bullets from becoming victims of the "French disease".

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became. Birth control was less and less associated with the suppression and regulation of sexuality and with harmful interventions in the female body. Advances in prevention helped to make some social democrats such as Kautsky and Grotjahn receptive to eugenic ideas. In the course of the Nazi autarky policy, not only car tires but also - less conspicuously - condoms were conquered by synthetic rubber; at times even condoms became part of a German special path. However, after 1945, the Germans also returned to natural rubber for this particularly sensitive product.[23]

To repeat a leitmotif of this presentation: epochs in the history of technology are characterized not only by innovations and the extent of their dissemination, but also by inhibitions and limits to mechanization and by the further development of traditional technology; from today's perspective, it is clear to what extent this still applies to the period discussed here. There was still a widespread tendency in German industry to use existing machines for as long as possible. The interest in organizational stability could hinder the introduction of innovations if they disrupted the existing company order. Apart from wartime, there was by and large no shortage of labor. Although there was a drive to intensify work in the wake of the reduction in working hours, there was not yet a general trend towards replacing people with machines wherever possible. At a VDI meeting in 1927, the rhetorical question was posed as to "where the validity of the technician was to be found in the many industries, in the textile, leather, wood, food, chemical-technical, brick-making, milling, ceramics, etc. industries. There was still no urgent need for scientifically trained engineers in many industries, even though "scientification" was a fashion in the 1920s that manifested itself in the founding of numerous institutes.

As technology still had new areas of life to conquer, it was possible to
Despite armaments, war and competition between world powers, technical development was still able to draw essential impulses from the dynamics of human needs or was at least relatively easily able to arouse the needs that technical innovations required. At the beginning of the century, Riedler even emphasized market orientation as a characteristic of the new technology, which distinguished it from that of the 19th century, when a good machine builder found his buyers even without rational production methods.[25] The "rationalization" of the 1920s and the reconstruction after 1945 both tended in different ways to subordinate technical development to the economy.

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And yet the connection between technological progress and war armaments was greatly strengthened in the first half of the 20th century. This gave the German public's relationship to technology a fatalistic quality. The First World War was certainly understood as an experience with the murderous aspects of modern technology, but at the same time it seemed to demonstrate the gloomy inevitability of technological progress. Oswald Spengler wrote that "the growing feeling for the Satanism of the machine is gripping the selection of the mind"; but shortly afterwards he glorified the "desperate struggle of technical thinking" against the power of money, which was carried by an elite of "steel-hard racial men of immense intellect". Friedrich Dessauer, a philosopher of technology with a background in X-ray apparatus construction, who was often used as a counter-authority to Spengler's pessimism, later confessed that almost all of his former colleagues had "perished in agony from radiation burns"; however, he did not attach any fundamental ideas to the evaluation and control of technological change to this, but rather coped with these abysmal experiences with a theology of sacrifice that is reminiscent of the slogans of endurance during the war.[26]

During war and hardship, environmental problems came last. The First World

The Second World War thwarted the efforts made by the majority of the German states prior to 1914 to pass an effective imperial law for water protection, while the Second World War led to the beginnings of an ecological approach to hydraulic engineering, which emerged from warnings about the "desertification" of Germany and was supported by Todt. The chemical industry, surrounded by the nimbus of the savior of the nation since the First World War, was more powerful than ever before. In times of crisis, smoking chimneys became a symbol of economic prosperity, while the phenomenal blossoming of nature in the Ruhr district during the Ruhr War (1923) bore witness to the decline of industry.

The blame for the Titanic disaster of 1912 was the subject of long and passionate public debate. The fatal side of the hunt for superlatives in shipbuilding, the urge for greater speed and the illusion of safety brought about by technical perfection was recognized by many. The greatest civil engineering disaster in Germany at this time was the Oppau accident (1921), in which an ammonium sulphate nitrate salt store exploded and 561 people were killed. The causes of this catastrophe became the subject of a Reichstag committee of inquiry, but remained obscure; the committee came to the conclusion that "the question of guilt could not be clarified". The attempt by the left-wing socialist Oppauer

"aniline proles", blaming the piecework and premium system for the catastrophe, did not resonate widely. The unknown residual risk of modern technology, or rather: the hypothetical risk that could be recognized from

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experience.

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The catastrophic extent of the effects of industrialization, which had been considered unreal, was unprecedented; but society was incapable of reacting to such warning signs. Even the well-known chronic harmful effects of industry were accepted as the inevitable tragedy of existence. Schenzinger's "Aniline", the best-selling German industrial and technical novel, which turns the history of German chemistry into a heroic epic, does not conceal the fact that "cancer creeps out of the aniline vapors."

Oswald Spengler, of all people, whose *Downfall of the West* (1918/22) led to an outlook on the modern "Satanism of the machine", became a popular lecturer in German heavy industry circles in the 1920s, and Karl Arnhold, the founder of the heavy industry Dinta (German Institute for Technical Work Training), was inspired by Spengler in his ideal of a new hard youth that would transfer the spirit of war into technology.[27] The cheerful technological optimism of the turn of the century was already passé after the mechanized mass slaughter of the war; what remained was a fatalistic Satanic cult of technology. An era accustomed to fatalism came to terms with the idea that high risks were inherent in modern civilization. The emergence of the "risk society" - if this term is to be accepted - can be dated to the early 20th century in Germany. The fatalistic attitude towards risk, which gave Reich German politics its disastrous character, also had an impact on technology.

2. The imperfect mechanization of war, the "quasi-dagger strike legend" of the technicians and the Blitzkrieg concept

Soon after it began, British Prime Minister Lloyd George characterized the First World War as a "war of engineers". And indeed, this war greatly increased the power-political prestige of technology among victors and vanquished alike. In the course of this war, technology - in the words of a German expert on technical warfare - underwent a development,
"which is something completely new and unprecedented in the history of war".
The architect Fritz Schumacher wrote at the beginning of 1918 that the war had transformed the masses into a human machine and irreversibly accelerated the move towards mechanization and rationalization. Above all, the positional war in the West with its material battles, the machine gun and artillery "drumfire", the gas and tank attacks was experienced by many participants as a technological shock, and by some as a technological frenzy. More than ever before, in Germany as in Western Europe, the technological

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nical progress and, in particular, progress towards "scientific" technology, large-scale technology and standardized mass production as an ineluctable constraint.

The German defeat gave rise to a formal "rhetoric of 'science as a power factor'" (Brigitte Schroeder-Gudehus). The conviction of the invincibility of technological progress was the belief that survived war and defeat in Germany the best, even if it did not necessarily make technicians more popular. VDI chairman Conrad Matschoß, the founding father of German technical history, even saw the war, where profitability played no role, as the best reparation for Reuleaux's verdict: "The war educates people to achieve quality. Expensive but good, not cheap and bad is the watchword here" - at least that's how it seemed to him at the turn of 1914/15. When the Stuttgart mechanical engineering teacher Carl von Bach, one of the independent spirits in the VDI, warned that the war was setting Germany back in terms of quality work, as the young generation was not receiving enough specialist training, he was met with fierce opposition and was "instructed that industrial production no longer depended on the worker at all, but on the organization, which was independent of the worker".[28]

Karl Helfferich, who as State Secretary of the Reich Treasury was involved in the organization of the war economy, claimed that "never" had "new inventions and new processes been thought up, tried out and put into practice in such abundance in such a short time", that "the usefulness of work and material had been increased and perfected to a similar extent" as in the world war. Walter Greiling, a man of chemistry, remarked that the "material battles of the world war" were "the first opportunity" to "test the effect of the technology of the new steel and the increased machine performance" - and certainly the capabilities of the new high-pressure chemistry. "But the technically superior form always wins," said Fritz Haber, the inventor of ammonia synthesis and one of the scientific heroes of the world war, justifying the gas war that he helped to unleash. And a Daimler general director was able to console himself: "No matter how many terrible things this war brought about, it was the greatest propaganda imaginable for automobilism." One could add: and even more so the Second World War, when millions drove cars for the first time and learned to drive! Franz Josef Strauß, who later became Federal Minister of Defense, believed that it saved his life that he took his driver's license in 1939 and joined the "motorized troop" had come.[29]

After 1918, the mechanization of the war led to the conclusion that the German defeat was partly due to inadequate technical equipment. This could be used as an accusation against German engineers.

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make yours. For them, however, it was crystal clear that the blame lay solely with the military's lack of appreciation for technology. The engineers, who felt undervalued within the army and had built up a bourgeois resentment against the aristocratic blasé attitude and incompetence of higher officer ranks, found an opportunity to vent their anger. As Erwin Viefhaus notes, the complaints "sometimes bordered on a quasi-dagger thrust legend - now directed against the military leadership of the empire"; sometimes they even exceeded this limit (and thus offered a counter-argument against the other, far more infamous dagger thrust legend!). In 1917, the VDI magazine wrote that it would be better to replace the military with engineers!

The haste with which the German gunpowder supply had to be organized by chemical synthesis shortly after the start of the war, the hardship with which the new technical necessity had to be taught to the military, the neglect of machine guns and tanks, and motorization in general, seemed to be proof enough. The Allied tanks in particular

Figure 27: British tank from the final phase of the First World War. The importance of these "tanks", which were still cumbersome at the time and had no turret, but in massed formation broke through the entrenched fronts and demoralized the enemy, was misjudged by the German army command for the longest time. Armour plate production had focused entirely on the fleet.

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were widely believed to have given the German Western Front the decisive push; this view was the starting point for Guderian's fight for an autonomous tank weapon. In retrospect, it seemed absurd that Germany of all countries, the land of Krupp steel and heavy engineering, should have failed due to the lack of a powerful tank weapon. The German engineer - as the VDI newspaper asserted in 1919 - would have achieved top military performance if only the Supreme Army Command had followed his lead. "In this respect, we have been defeated militarily and not technically, as militarism has fallen into the arms of German technology." As early as November 1918, the "Bund technischer Berufs- stände", which became the "Reichsbund Deutscher Technik" (RDT) in 1920, acknowledged the fact that engineers only played a minor role in the war.
"advisory voice" was "not the least" to blame for the military collapse. The irritable Riedler proclaimed with apodictic acerbity while still under the frantic impression of the German defeat: because "the technical spirit was lacking in precaution and leadership" and had been "banished to the narrowest, most independent auxiliary service", "every victorious advance soon became a dead run".

"Even the leading basic ideas of the entire warfare were technically wrong [...]: What had to be spared the most, the people, because they had to fail the quickest in terms of numbers and strength, was used ruthlessly, superhuman things were demanded of them and also accomplished for an incomprehensibly long time. The technical means were misjudged: the highest fire effect at the right time, the machine guns as a weapon of the smallest combat units and the greatest mobility with the best technical means, that was missing or was not properly appreciated."

In this writing, however, he unintentionally demonstrated the dubious use of technical expertise for military forecasts when he expressed his unwavering belief in the Zeppelin and his conviction of the military futility of air raids.

Haber, by no means shocked or disillusioned by the gas war after 1918, expressed regret to the officers of the Reichswehr Ministry in 1920 that the gas war had not been thought of before 1914: then German chemistry would have "achieved" what it had "achieved" during the war,
"easily overtaken". Bredow, the "father of German radio", assured that the war would have been more successful with better radio equipment. Ehrhardt, who recalled that his recoilless gun had been rejected by the army command for years with the standing phrase "far too complicated", explained that the war could have been won by a hair's breadth - if the relevant circles had understood early enough that "every modern war is a technical war". Dessauer believed that the "disregard for technology was at least "one of the causes of the German defeat".

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There are indications that the accusations against the military were even harsher internally than in public, where patriotic considerations were taken into account. Even former Chancellor Bernhard von Bülow, who preferred to forget his own responsibility for the course of events, sounded the same horn.[30]

The Second World War seemed to leave behind the warning - not only in the eyes of industrialists and engineers - that the economy and technology could not be effectively managed by military authorities, but only by experts from within their own ranks. This view was the prevailing doctrine during the Second World War. Even at the beginning of the war, Hitler himself repeatedly affirmed "that the economy must be managed by an economist and that the soldier must confine himself to making demands". Industry could afford - as General Thomas, the head of the military economic staff of the OKW, lamented - to leave the
"Battle cry against the soldier". Under Speer, the war economy was - despite the National Socialist "primacy of politics" - practically directed by the organizations of industrial self-administration. This could lead to industrial interests virtually thwarting military needs in armaments production. When large gaps in industrial armament became apparent in the summer of 1944, Speer explained this misdirection of weapons production with an astonishing openness that also reveals his identification with the industrial perspective: "From our point of view, the production of a tank or a rapid-fire gun is industrially more attractive than the production of a light infantry gun or carbine or machine gun."[31] A more impartial study of the First World War and the period before it would have enabled the dangers of such industrial primacy to be recognized early on.

The First World War seemed to teach that only the consistent use of new technology could help win a future war. This was Guderian's basic idea and became the recipe for success of Hitler's Blitzkrieg strategy: to make up for Germany's numerical inferiority through kinetic energy and speed by means of new technology. The sceptical army command of the 1930s was again accused of a lack of technical understanding.[32] However, a much more important lesson of the First World War could have been the realization that the unpredictability of the outcome of the war tended to increase due to the mechanization of war and that the military value of new technology could not be reliably predicted in an emergency. This lesson was deliberately ignored by technology enthusiasts in particular.

Is it true that the German general staff lacked a relationship with technology before 1914? The Schlieffen Plan was virtually a model of technicist thinking, and interest in technical innovations had

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was already a tradition at the time. Not only the Prussian fighting morale, but also the percussion-pin rifle invented by the Thuringian gunmaker Johann Nikolaus Dreyse was considered the winner of 1866; this was no isolated innovation at the time, but had sparked "a veritable fire of enthusiasm in the weapons technicians of the whole world" and triggered a "flood of inventions". In 1878, Friedrich Engels believed that no "new progress of any revolutionary influence" could be expected in the technology of land warfare since the percussion-pin rifle - so much can the fascination with current technology paralyze the imagination for future possibilities! - but industrialists and the military knew better. Siemens, for whose business the war of 1870/71 had come as a pleasant surprise, had always found the military receptive to electrotechnical innovations since that time.

After 1890, Michael Geyer recognizes a turnaround in Imperial German military policy from personnel-intensive to material-intensive armament; the technology race between cannon and armoured plate began. The existing state gun production and armaments organization was no longer able to cope with the new requirements; Krupp's monopoly position as a
The Reich's "armaments forge" reached its peak; in Essen, the development of higher quality steel and guns was now pursued with scientific systematics, and Krupp's technical developments determined Berlin's armaments policy. It was not indifference to advances in armaments technology, but a remarkable degree of dependence on industrial "experts" caused by the pursuit of the latest technology that characterized the army leadership of Imperial Germany.[33] Of course, it was not technical progress per se that was achieved in this way - because there is no such thing - but a certain type of technical progress that corresponded to leading industrial interests.

With dry sarcasm, Chief of the General Staff Schlieffen made it clear that the "most glorious triumphs" of weapons technology by no means cast an attack in a rosy light: "It was not easy to say how one could strike down and destroy one's enemies with these effective weapons. How to avoid annihilation oneself was a problem that was not easy to solve. "[34]

But the new technology - then as later - left several paths open to the imagination. The more diverse the technology becomes, the greater the scope for justifying preconceived positions with technical arguments and thus providing them with a semblance of factual logic. If the massed frontal attack no longer stood a chance in the face of modern firepower, then for those who still wanted to go on the offensive, the way out was the broadly spread front and the huge encirclement, directed by a new-style commander who could not make eye contact with the enemy.

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the fighting men "in a house with spacious writing rooms",
"where wire and radio telegraphs, telephones and signaling devices are at hand, crowds of motor vehicles and motorcycles, equipped for the longest journeys, await orders". Schlieffen drew the fallacious conclusion from the technicist idea that the modern economy was a "gear train" that would come to a "standstill" through war that a modern war would lead to a quick decision out of economic necessity; under these circumstances, the economic preparation of a long war was unnecessary.[35]

General Bernhardi, one of the worst warmongers before 1914, was not wrong to recognize in Schlieffen a "mechanical conception of war", which made the commander "a kind of machinist".[36] It can be added that the Schlieffen plan had the rigidity of the mass production and bureaucratized large-scale organization of the time. It was based on the illusion that a major war could be programmed in advance and organized like a gigantic clockwork mechanism; the encircling movement planned by Schlieffen in the west with a slight retreat in the south has been compared to a giant revolving door. The first disastrous consequence of the grand plan was the political inability to maneuver that led the German imperial government to disregard Belgian neutrality. Here, as elsewhere, technocratic thinking in no way led to a secure judgment of the real possibilities of technology.

This also applies to the technicians themselves. On the whole, it is not clear that technical journalism at the beginning of the First World War was more forward-looking in its own field than the military strategy; rather, one notices the perspective of the respective technology sector and the tendency to confuse the technically interesting with the militarily useful. An editorial in a mechanical engineering magazine *Krieg und Technik* from the end of 1914, which praised the military significance of new technology in the highest terms, particularly emphasized the heavy Krupp guns, submarines, airships and electrical engineering, but ignored chemistry, the machine gun and motor vehicles.

Matschoß regarded the war as a "trial by fire" for the automobile, but only mentioned "armoured cars" in passing and in last place. When he stated "expensive but good" as the motto of the war, this was a technical conceit that belonged to a different world than that of material battles. In the course of the war, cheap mass production with materials of the lowest possible value was the most important thing. During the Second World War, even a VDI representative warned against the "disastrous 'obsession with precision'". At the front, people appreciated simple and robust technology that still worked in rain and mud and whose components did not fit together with such precision,

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that nothing more could be done with spare parts from scrapped material. The "T-34 shock", the superiority of the Soviet infantry fighting vehicle, which was almost indestructible due to its simplicity, later haunted many war memories.[37]

If the machine gun was neglected by the German army leadership until 1914, it was because it seemed "at most suitable as a defensive weapon in fortress warfare". No less a figure than Ludendorff dismissed the heavy machine guns with their protective shields as the "death of any offensive" shortly before the start of the war. Machine gun fire with its "waste of ammunition" was regarded as a typical French or American firing method. It was remembered that in 1870/71, "a few well-aimed shots from our artillery" had been enough to "put a stop to the French Mitrailleuses, the machine gun's masterminds".

For this reason, increasing firepower through heavy artillery - in line with Krupp's technical progress - promised more success. Artillery was and remained particularly attractive to German engineers, as it corresponded to the ideal of "scientific" technology: "Artillery is the most complicated and at the same time the most highly stressed of all weapons and contains within it the exhaustion of experience, knowledge and expertise from all branches of mathematics and mechanics, physics and chemistry." It was the same fascination that became the driving force behind nuclear and rocket armaments in the Second World War. The course of the First World War, however, already showed the military irrationality of the obsession with the technical superlative: heavy artillery soon reached "an upper limit of caliber, effectiveness and firing range", beyond which a further increase such as the "Dicke Bertha", Krupp's famous "Paris gun", only meant waste: *upscaling* as irrational megalomania![38]

The strategic concept of "mass artillery" and the artillery

"Mass rapid fire" with the unprecedented mass slaughter - more than 50 percent of all war deaths fell victim to massive artillery fire - matched the mass steel production that was the strength of German heavy industry. The construction of tanks, on the other hand, was at odds with the German industrial structure of the time: heavy industry and the engine industry, which had to work together, were still two different worlds. As Eckart Kehr notes, the cannon was not an "explosion engine" for Krupp, but a "cast steel block". A connection between the steel industry and the fleet, on the other hand, came about more easily, all the more so as at the end of the 19th century - after a "torpedo frenzy" as late as the 1980s - the trend towards size prevailed in warship construction, although Admiral Tirpitz, the *spiritus rector* of Wilhelmine naval mania, had begun his career as a torpedo man.[39] A powerful *community* formed around the battleships, which was supported by the heavy industrialists.

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to the "naval professors"; not about alternative strategies for the time being - not until the war over the fatal submarine weapon.

The fascination with the enormous shape dominated the early days of German aviation. While the idea of the dirigible airship was a prime example of unsound project engineering for the old Siemens, Count Zep- pelin, who flew his motorized airship over Lake Constance for the first time in 1900, was celebrated like no German inventor before him. The tenor ranged from "ruler of the skies" to "greatest German of the 20th century". The hugely inflated, yet extremely vulnerable "Zeppelin" seemed like a symbol of the Wilhelmine era. As late as 1929, the
"Deutsche Führerbriefe" - a "private correspondence" of influential business circles - was inspired to new German dreams of world power by the Zeppelin's circumnavigation of the globe at the time: this global technology, which would soar high into the skies, would also bring about a "change in the shape and form of politics".

All the more remarkable is the speed and consistency with which German armaments policy switched to the promotion of powered aircraft from the last years before the war, when its military advantages could no longer be ignored.

During the war, the German military took delivery of no less than 47,637 aircraft, including around 150 different types from 35 companies. Despite this diversity and the workshop-like production methods of the mostly still small companies, a kind of large-scale production already came about in some cases. The Supreme Army Command even gave aircraft construction priority over tank production. From the still predominant perspective of the infantry, the Luftwaffe was a welcome protection, while the combination of infantry and tanks required a new fighting style. The "cavalry of the air", in which it was still man-to-man combat and individual firepower could be precisely quantified, became the most popular of all branches of the armed forces during the First World War. The "chivalrous" single combat at altitude was befitting for those social elites who had previously preferred cavalry. While the public mainly paid attention to the battle between the airmen, the bombing war from the air had already begun at that time, and this was extended to the civilian population as a matter of course. The possibilities of technology overtook the centuries-long tradition of the law of war and international law, one of the core elements of which had been the limitation of acts of war to the combatants.[40] In many respects, the temptations and apparent constraints of technology influenced the armament and conduct of war in a way that was fatal even from a purely military point of view. The prototype of a technical-industrial dynamic that had disastrous consequences from a foreign policy and military point of view was the Wilhelmine naval armament, which in the

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The German army, which gobbled up 60 percent of the German armaments budget in the final years before the war, had virtually no function in the overall German strategy. As unbelievable as it may sound, Schlieffen and Tirpitz made their major land and sea war plans without any mutual coordination! In the hopelessly deadlocked military situation of 1916, submarine warfare promised a technical way out for all those for whom a political way out - the initiation of peace negotiations - was not an option. Reich Chancellor Bethmann Hollweg opposed the unlimited submarine war with all his might, which also endangered civilian shipping and provoked the American entry into the war. From a technical point of view, however, the maximum use of this "masterful weapon" seemed like a dictate of necessity and went against the "nature of this weapon" to sink merchant ships without warning and not pick up any shipwrecked persons.

The use of the first gas weapon used at the front, chlorine gas, which caused asphyxiation, was based on Haber's suggestion, while the military always remained skeptical about chemical weapons. On the western front, the wind from the west generally prevailed: bad for the Germans as soon as the Allies also used poison gas; only exaggerated ideas about the superiority of German chemistry could lead people to believe that the West was incapable of using gas weapons. In October 1918, shortly before the end of the war, Adolf Hitler was the victim of an enemy gas attack, which led to his temporary blindness; it was then that the hateful fantasy of destroying the Jews with gas first germinated in him.

All in all, poison gas proved to be a double-edged weapon which, without having a decisive effect on the war, triggered a desire for revenge and retaliation. As Solzhenitsyn notes, the war was waged by the Russians "without personal feelings of hatred", "until poison gas was used". Nevertheless, after the end of the war, some military journalists were obsessed with the idea of a future chemical war, regardless of the outlawing of chemical and biological weapons in the Geneva Protocol of 1925. There was certainly a rational and emotional aversion to the gas weapon both inside and outside military circles; however, this corresponded to a way of thinking in which chemistry was the epitome of progress. In 1919, Colonel Bauer wrote in a memorandum that "chemical warfare agents" were "not an accidental product of war, but a necessary outcome of the conditions created by the development of weapons technology".[41] A new form of technological determinism! In the Second World War, however, poison gas was only used against the defenceless Jews.

The increased motorization of technology provided pseudo-substantive arguments for aggressive war. According to a 1938 handbook, the technological war of the future would almost certainly be a preventive war, because the

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The trump cards of the new technology were best played in a surprise attack. Guderian's war concept, which led to Hitler's Blitzkrieg strategy, was inspired by motorization and wireless radio: "The achievements of technology virtually force themselves on the soldier." Never before in history had "mobility" had such opportunities as it did now. Guderian's call for an armored weapon that could operate independently of the infantry sparked a ten-year controversy in German military circles. There was still the prejudice: "Technology makes people cowardly." More serious were the concerns about the dependence on technical experts that motorized warfare placed the generals in. Fritsch, who was appointed Chief of the Army Command in 1933, assured Guderian: "The technicians are all lying." Based on the experiences of the First World War, there was no justification for an independent tank weapon. Around 1930, the tank presented a pitiful picture on German maneuvers; as late as 1938, an expert judged that the "tank spectre" had lost its terror and that anti-tank defence now had technical superiority. Tank units only became operational when they included motorized troops of all weapons; motorization was also a comprehensive process in the army. However, there was no doubt that the strategy based entirely on new technology had the "Führer" behind it. Hitler confessed: "I am a fool for technology. "[42]

The initial successes of the German armies in the Second World War seemed to confirm Guderian in a triumphant manner; however, the outcome of the war did justice to Guderian's opponent Beck, who did not want to believe that a major war could be won in blitzkrieg style. Despite the major tank battles on the Eastern Front, Soviet military doctrine drew the conclusion from the Second World War that the infantry was the decisive type of troop. However, the structure of the Bundeswehr, which was oriented at least as much towards industrial as military aspects, followed the Guderian tradition, even to the point of dispensing with infantry units.

Alongside the tank, the airplane was the technical basis of the Blitzkrieg; the air force, conceived as a tactical instrument under Seeckt, was designated as a strategic weapon by Göring. During the Nazi era, aviation research reached dimensions that surpassed anything previously seen in technology research; in 1944 it comprised around 10,000 employees. But the inadequacy with which the bloated research was translated into practically usable technology was phenomenal and already anticipated the later dilemma of *"Big Science"*. No other weapon was born so much from the spirit of blitzkrieg as the Stuka (dive bomber), which swooped down on its target like a bird of prey; but the obsession with dive bombing still dominated aviation technology at a time when blitzkrieg had failed; long

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The use of bomber aircraft was neglected. Even more so, German armaments fell behind in defensive radar technology. The role of the Luftwaffe in the Second World War is reminiscent of that of the fleet in the First: it was the most expensive weapon, consuming up to 50 percent of the German armaments budget in the final years of the war, and became the "greatest disappointment". It did not bring victory, but legitimized the Allied area bombardment of German cities.

The Nazi German "uranium project" had even fewer chances; however, it could very easily have led to the first atomic bombs being dropped on German cities. The type of leader that the Nazi system brought to the top showed less ability to manage large-scale scientific and technological projects than the American Roosevelt administration. The spirit of the Nazi leadership, which placed will above intellect, was not conducive to the emergence of intelligent and effective technology networks. Nevertheless, Goebbels' "Wunderwaffen" propaganda was still very successful at a time when many people no longer believed much else in Nazi propaganda: so deeply was the belief in the wonders of technological progress anchored in the population.[43]

The conviction that war is the father of all things is a recurring theme in modern technological history. The First World War seemed to demonstrate the truth of this conviction impressively and on a historically unprecedented scale. Leuna, the gigantic chemical plant that was built by BASF during the First World War to produce explosives, produced fertilizers in peacetime using the same method of ammonia synthesis. Insecticides for agriculture were developed from the poison gas during peacetime. In 1915, the Golpa-Zschornewitz power plant was built near Bitterfeld to supply the Piesteritz nitrogen plant, which consumed twice as much electricity as the whole of Berlin at the time. At 128 MW, it was the largest power plant in the world at the time, ushering in "the era of large power plants and the integrated economy". Motorization and aviation were given a powerful boost by the war, especially in Germany, where civilian impulses were still relatively underdeveloped or hampered by resistance before 1914. After 1918, however, the ban on military aircraft construction decreed in Versailles proved to be a productive impetus for German civil aircraft construction!

Before 1914, Germany was the only major industrial country that did not have its own *aluminum industry*. Although this light metal had originally been discovered by the German chemist Wöhler, it first excited the French public, while people in imperial Germany mocked the fact that the "grande nation" was already seeing its entire army "in flashing aluminum helmets and aluminum cuirasses". The lightweight for the (from a German perspective) easy-going nation! In 1909, aluminum

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German imports were more than 18 times higher than exports. At that time, the electricity-intensive aluminum industry was considered to be a branch of production only suitable for "car countries" and regions rich in hydropower. In 1917, however, a large-scale aluminum industry, the Vereinigte Aluminiumwerke (VAW), was created with funds from the Reich. The light metal was valued during the war partly as a substitute for copper and after the war - following the loss of the Lorraine minette - as the "only metal from domestic soil"; however, its forced use in the war had not promoted the confidence of civilian buyers in the new metal. Aluminum was not restricted to certain areas of application from the outset, but had to find its own demand. In the course of the 1920s, it became the "universal metal" that made household appliances lighter. In the wake of the rearmament of the Luftwaffe, the German share of world aluminum production rose to 32 percent by 1938.[44]

The "complete revolution" that the war - especially the war at sea - triggered in *wireless radio had a* quicker effect: whereas this had previously been the "business of a few initiates", "hundreds of thousands" now came into contact with Morse code, many of whom continued to use radio as a sport even in peacetime. But radio and especially *broadcasting in* Germany, like the telephone a generation earlier, was quickly understood as a state matter and a technical necessity for cooperation between the state and industry, unlike in the USA. Unlike two generations later with computers, the amateur movement as a dynamic force of technical development only had a very temporary effect. The situation during the war and post-war period countered monopolization by the state. Both old and new rulers agreed on this. For Postal Minister Stingl (1923), private gadgetry with radio equipment was a bad foreign fashion, and for Reich Chancellor Bauer it was also associated with the constant danger of national treason. Prussian Interior Minister Severing feared that if anyone could use the radio at will, it would be "a trifle to proclaim the monarchy". At the end of November 1918, representatives of the Reichspost, the Ministry of the Interior and the Central Radio Directorate met at the War Ministry to discuss the regulation of wireless radio in view of the impending revolution. The initiator of the Central Radio Directorate, engineer Meyenburg, wanted to free this new medium from the control of "calcified officials". But Hans Bre- dow, the coming strong man of German radio, "like all pioneers of wireless radio an obsessive" (Wolfgang Hagen), disproved the cliché of the "calcified civil servant" as impressively as possible.[45]

However, all these innovations as such were not due to the war
At best, it provided an impetus for accelerated dissemination, mass production, typification, larger dimensions and politicization.

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rization. Under the pressure of the war, the implementation of industrial standards, which in part ran counter to the individual production lines of many entrepreneurs and the diversity of needs and only made slow progress under civilian conditions, was finally pursued systematically and on a national scale - the German Standards Committee was founded in 1917.[46] Mechanization, which released men for military service and allowed unskilled women to take the place of skilled workers, now became a patriotic duty; the machine industry, which had panicked at the start of the war, realized after just a few weeks what a unique opportunity it now had. The truck drivers who destroyed the roads not yet equipped for such traffic and caused the houses to shake were given free rein during the war; the damage they caused to the road surface had to be borne as war damage. It was only after the end of the war that local residents and communities were able to vent their anger about the "plague of cars".

During the war, it was not only German technicians but also housewives who proved inventive when it came to procuring replacement materials. *"Ersatz"* became a Germanism that penetrated other languages. But after the end of the war, this "substitute" past clung to these fabrics as a flaw, even if they were technically highly developable synthetic fibers. Vogler's astonishing statement in a memorandum written in October 1918 shows just how small the creative effect of armaments and war was in the steel industry of all industries: "In the last 15 years, the German iron industry has achieved hardly any notable successes in scientific terms, both in the improvement of its qualities and in the further utilization of by-products".[47]

From the First World War to the Second World War, the reverse experience was at least as impressive as the effect of the armaments orders challenging the highest technical performance: that high-quality war armaments could only be guaranteed with a broad and solid basis of civilian technology, as maneuvers could never even come close to testing the quality of technical components to the same extent as constant use in everyday civilian life. Even the head of the War Raw Materials Department, Lieutenant Colonel Koeth, in 1917, to the satisfaction of the industrialists, "attached the greatest importance to the fact that one must not think [...] that the preparations for war would have to be so strong that they would affect our peacetime economy". For Guderian, it was self-evident that "the development of armoured motor vehicles could only take place with close reference to and alternating inspiration from commercially available motor vehicles of all kinds". Josef Winschuh, a journalistic spokesman for the Ruhr industry, explained in 1940 with great emphasis and detailed evidence that the German weapons were "only so good because they had all the material experience and con

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The "progress in production that we are making with our peace policy"; as pure "weapons smiths", industrial companies would "calcify and rust". This was presumably a dig at Krupp, which had indeed lost its leading technological position to other Ruhr companies in the 20th century.[48]

The industrial resistance to a predominant specialization in armaments orders was compounded by another circumstance that had become increasingly important since the end of the 19th century. The more armament demanded technical superlatives of a certain kind, the more it required a degree of specialization on the part of industry that distanced the necessary production technology from the production facilities set up for civilian purposes: therein lies a dilemma of "high-tech" armament, which became increasingly acute as long as no civilian demand was found for this cutting-edge technology. The Wilhelmine naval armament did not bring a resounding technical advantage to merchant and passenger shipbuilding, where British superiority remained far greater than in warships until 1914. Pajeken, the head of the Loewe machine tool factory and the leading expert on American production methods at the time, was impressed by a major order for special machines for weapons production in the 1990s.
"These, according to Pajeken, "hinder progress in the technical design offices and in the workshops and cut Ludw. Loewe & Co. off from the market for machine tools at home and abroad". The company boss eventually proved him right. Even during the Second World War, military equipment in Germany was predominantly manufactured in production facilities that could also be used for civilian purposes.[49] The full development of a "high-tech" armaments industry, which was completely detached from civilian technology, only characterized the most recent period in the history of technology, when, paradoxically, the "spin-off" myth - the belief in the fruitful "waste" of cutting-edge military technology - flourished most abundantly.

3. Electrification and chemical synthesis as technology paths and group-forming processes

The *Lustige Blätter* rhymed on New Year's Day 1900: "We need a new fludum/Hail to you, electric seculum!" On closer inspection, the electrical industry, like other sectors, was going through a crisis around 1900 - it is sometimes all too tempting to emphasize the newness of technology after the turn of the century, inspired by secular literature. And yet there was a reason for the way contemporaries felt. The chemical and

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In the early 20th century, the electrical industry was different from the time when electricity still meant telegraphy and chemistry only meant soda and dyes. In the 20th century, both branches of technology could no longer be identified with specific products. They had become *"technologies"*: universally applicable processes that required specific expertise.

This was something new in the history of technology. The scope of application of the steam engine had been limited, and even more limited if the aim was to improve efficiency. Electrification and the synthetic production of new materials, on the other hand, began to gain ground from the end of the
The electricity of the 19th century can be depicted as an infinite process: if at first mainly in the imagination, then over time also in reality. As long as direct current prevailed, electricity was only available on a local scale and only for

Figure 28: Awakening of a mock-dead person through electric shocks from a Voltaic column. Ever since Galvani had discovered from twitching frogs' legs that electrical impulses act in organisms, there had been speculation as to whether the "life force" was of an electrical nature, and more and more therapists experimented with weak electrical currents. In the "nervous age" towards the end of the 19th century, electrotherapy experienced a veritable boom - both in Germany and the USA. But it was precisely the triumph of high voltage current that led to a crisis: accidents with high voltage current meant that electricity was now associated with danger to life.

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specific fields of application; the alternating current made them universally available. This established a "new type of technical thinking": a way of thinking that turned "from the individual work to the principles, to the general laws". Electrical engineers were a different type to conventional mechanical engineers: it was their job to deal with invisible forces.

The shape of technology also changed in the eyes of the public. "Technology" had not been an issue in this abstract form in the 19th century; now considerations of "man and technology" began,
"Culture and technology" became fashionable. Abstract technology could also be used in a figurative sense; numerous composites emerged: from the
"Prayer" to "psycho-" and "love technique". Thinking about technology did not necessarily become clearer through abstraction. It was possible to talk about "the" technique in a more sweeping way than about concrete techniques. "Technology" could be ascribed an all-encompassing constraint that would have been difficult to concretize in individual techniques.

The progress of a technology that increasingly conquered all areas of life was linked not only to science, but also to the infinity of practical experience - especially consumer experience.
"Even with the best scientific prerequisites, it is not possible" - according to the Bosch commemorative publication in 1936 - "to develop an ignition system or a flywheel starter [...] into a marketable product." In his biography of Robert Bosch, Theodor Heuss, who later became German President, vividly described how Bosch fought for his magneto ignition system against Daimler's glow-tube ignition system by publicly sounding the alarm that glow-tube ignition had to be abandoned.
"make every car burn once", and thus aroused Daimler's hatred. The racing drivers, who made extreme demands on the igniter with their roaring engines, helped the Bosch igniter to victory, just as the authors quickly ousted the steam cars and electric cars - initially, from a purely technical point of view, quite formidable competitors to the cars with explosive engines - from the arena. Marketing and consumer demands emerged as factors of technical innovation, often in conflict with development paths that followed the previous logic of technology. However, some car manufacturers also allowed themselves to be carried away by the speed frenzy in an entrepreneurially irrational way. Fritz von Opel caused a sensation in the 1920s with his rocket racing car; meanwhile, he made his money with his cheap car "Laubfrosch", which was an imitation of the Citroën.[50]

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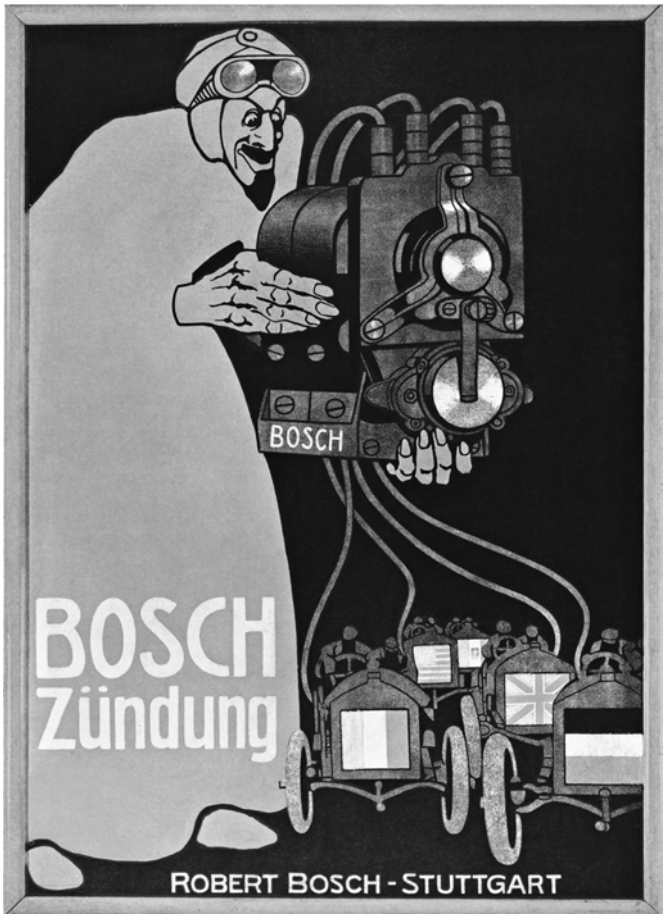

Figure 29: Advertisement for the Bosch igniter by Lucian Bernhard, 1911. A few years earlier, when Bosch production was barely keeping pace with demand, Robert Bosch had considered advertising a waste of money; but when the competition became fiercer, he hired the talented Art Nouveau graphic artist Bernhard. The advertising graphics reveal - note the racing cars with different national colors at the bottom right! - that Bosch was primarily speculating on racing drivers (and those who wanted to become one). The motorist eagerly reaching for the Bosch ignition is no "Otto Normalverbraucher", but a mixture of sportsman and demonic playboy!

When IG ("Interessengemeinschaft") Farben was founded in 1925, the name of this largest chemical group in continental Europe was already an understatement. The ambitious investment policy of the new company management focused so much on rubber and fuel synthesis that the traditional dyes sector was neglected, although it was still the mainstay of the company.

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solid basis of the chemicals business and reinsurance against the risks of high-pressure synthesis.

The first new area outside of tar dyes, which organic chemistry began to develop more strongly at the end of the 19th century, was *drug and pharmaceutical production*, which was chemically closely related to dye production. The first "bestsellers" of the Hoechst pharmaceutical department were the fever- and pain-relieving preparations Antipyrin and Pyramidon, the The "first really big hit" in pharmaceutical development at Bayer was aspirin, which served the same purpose. Far greater hopes were pinned on the tuberculin discovered by Robert Koch, whose manufacturing rights were acquired by Farbwerke Hoechst in 1892; but this drug, which was supposed to defeat tuberculosis, the worst epidemic of the time, and for which Koch had demanded the then fantastic sum of three million Reichsmarks from the Prussian government, proved to be a failure. Salvarsan, the cure for syphilis, led to the connection between Koch's student Paul Ehrlich and Farbwerke Hoechst.

However, many doctors were still suspicious of the new chemical products. Around 1900, Germany in particular experienced the first boom in naturopathy, from whose point of view the pill doctors were a species doomed to extinction. Even from the point of view of leading chemists, "iatrochemistry", the chemistry of doctors, characterized a pre-modern era of chemistry founded by Paracelsus. The pharmaceutical business was long regarded as uncertain, even though a preparation, once successfully launched, could fetch "more than a hundred times its cost price" when sold. In retrospect, IG Farben's investments in the pharmaceutical division were remarkably low in terms of the potential profits: the expansion potential of this particular branch of production in a tablet-addicted affluent society was not yet foreseeable.[51]

Before 1914, German chemistry presented itself almost exclusively as a paint producer. A generation later, however, its self-portrayal had changed radically. In 1938, a survey of around 40 leading men in German chemistry revealed a panchemism and a belief in the universal applicability of chemistry. Materials research was given special opportunities for the near future: "Here, special materials will be developed for every application in place of the universal materials steel and wood that have been used up to now." However, the prediction that steel would be replaced by plastics was premature. The exaggerated prophecies in the early days of the National Socialist four-year plan were inevitably followed by disillusionment. Hitler said in 1941 that it was "impossible to produce everything we lack ourselves by synthetic processes or other measures".

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to want": this was one of the reasons he used to justify the attack on the Soviet Union.[52]

In 1901, Wilhelm Ostwald, a pioneer of physical chemistry - an interdisciplinary discipline that gained in importance after the turn of the century - discovered the acceleration of chemical reactions through catalysts. The discovery was in line with the "speed" enthusiasm of the turn of the century. Catalyst research, which remained at the "methodical trial and error" stage in the following decades - around 20,000 tests were carried out at BASF to determine a usable ammonia catalyst - steadily gained in importance, with German laboratories leading the way. It was a time in which German chemistry, which was inherently more specialized in expensive quality production, shifted more towards mass production on a large scale and the acceleration of production processes.

Nitrogen production, which was given a huge boost by the First World War, brought a kind of large-scale technology to chemistry that was more reminiscent of the blast furnaces of heavy industry than the previous production facilities of the tar dye industry. Cross-connections between steel and chemistry became a key to the success of high-pressure synthesis, which the older generation of chemists had not been comfortable with. Elsewhere, too, the further development of the chemical industry was tied to close cooperation between chemists and engineers, which ran counter to the tradition of German chemistry at the time and required a lengthy process of familiarization and, in some cases, a new generation of chemists. Even within IG Farben, influenced by this, there were "major differences in the methodology of technical thinking" (Win- nacker).[53] In heavy industry, chemistry and electrical engineering became key disciplines, as the materials iron and steel came under attack by electric steel and the progressive development of new alloys.[54] Around 1918, systematic research was also considered the order of the day in the Ruhr. Unlike in England, heavy industry in Germany had not yet become the "old" industry that contrasted with the "new" industries.

Similarly significant and characteristic processes such as the emergence of cross-connections between steel and chemistry in the early 20th century was the crossing of boundaries between the chemical and electrical industries, between the electrical sector and mechanical engineering and also the automotive industry. Electrochemistry had already provided the impetus for the quantum leap in power plant capacities and RWE's entry into lignite in the final period before 1914: the Goldenberg power plant, completed in 1914 and at times the largest thermal power plant in Europe, was built together with a neighboring electrochemical plant.[55]

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The decisive step in the implementation of the electric drive in the manufacturing industry was the transition from the electric group drive to the individual drive. As a group drive, the electric motor had only replaced the steam engine and still required mechanical transmissions; as an individual drive, it could be individually controlled and technically integrated into the machine. This was the engineers' finest hour, because this was where the experience of the master craftsmen, who had previously dominated the practice of mechanical engineering, reached its limits. Above all, however, the single drive ensured a steady speed, while the speed slowed down with the growing chain of transmissions. In 1930, Carl Köttgen, General Director of Siemens-Schuckert-Werke, proclaimed the "basic law of drive technology" at the Berlin World Power Conference: the supply of motor power as directly as possible instead of via transmissions. Nevertheless, the introduction of this innovation took decades; even at an electrical company like Bosch, the group drive still prevailed in the 1920s. As a rule, transmission systems were retained as long as they functioned satisfactorily: The German entrepreneurial mentality was still reluctant to scrap usable production equipment.

The electric motor facilitated the mechanization of the internal transport, not least the lifting of loads: a large traditional sector of heavy physical labor, which until then had shaped the physiognomy of the worker and stood in the way of a smooth organization of the production flow, could now be progressively reduced, even if a lot of manual labor still remained. The individual electric drive provided a freedom in the reorganization of the production process that had not been known since the introduction of the steam engine, because the production facilities no longer had to be centered around a single power source. However, this freedom was generally not used; entrenched ideas of order were tenacious. Even with individual drives, the machines often stood stubbornly in a row, just as the steam-powered transmission systems had required. Flow work was often introduced in a rigid form that corresponded more to the age of steam than that of electricity. The individual electric drive contained the technical possibility for each worker to determine his own working speed; but the realization of this opportunity ran counter to what had been understood for decades as "rationalization". Direct current motors could be controlled most flexibly; but such flexibility was often not wanted and did not help to stop the retreat of direct current.[56]

In electricity advertising, which focuses heavily on the public, governments and municipalities, the electric motor was praised as the savior of the small business, the business that had replaced the steam engine.

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had not been able to afford. In fact, electricity marked a new phase in the mechanization of small and medium-sized enterprises. In the period up to the First World War, when large companies still generated all the energy they needed themselves, public power stations were still largely dependent on small businesses as consumers of electricity. This was the main reason behind the propaganda that praised the electric motor as the savior of the trades. As one critic of this campaign noted in 1896, "the small tradesmen themselves, who must first and foremost know where the shoe pinches them, very rarely demanded small motors". Even a generation later, the profitability of the electric motor in small businesses was not beyond all doubt: As the Reichstag's economic inquiry in 1930 determined, in typical cases the small business only used its electric motor for two hours a day. Electrification was not the zero hour in the mechanization of crafts; as was stated in Lippe in 1914, craftsmen in the countryside "apparently did not need the new energy supply, as they could generate power more cheaply with petrol, spirit and petroleum engines". It was not electricity that saved small-scale industry, but the ever-present demand for such goods and services, which did not give large companies an advantage over small businesses that were flexible and close to the market.[57]

A group of engineers from Melbourne who undertook a trip around the world in 1912,

rated Berlin as "electrically the most important city", at least within Europe. At that time, Berlin had become an "electropolis"; in the 1990s, the electrical industry had overtaken the previously leading mechanical engineering industry. The construction of "Siemensstadt" - the name had officially been in use since 1913 - documented the company's drive for expansion after the crisis of 1902. It was not until the 1920s that households in Berlin were electrified across the board, together with the wiring and underground installation of power lines. Although it was also commonplace in the electrical industry to complain about the narrow-mindedness and risk aversion of the German authorities, cooperation between the electrical industry and the state in Germany was remarkably quick and effective by international standards. Berlin led the way and became a model for a centralized energy supply, which provided the electricity company with monopoly rights and the municipality with income and made the sensational reduction in electricity prices from 30 to two pfennigs per kilowatt hour profitable through strong expansion. This process is all the more remarkable given that, initially, countries rich in hydropower and poor in coal seemed predestined for large-scale electrification. The sensation of the Frankfurt Electrotechnical Exhibition of 1891, the power line from Lauffen to Frankfurt, had demonstrated the combination of electricity and hydropower,

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just like Oskar von Miller's later Walchensee power plant project. But in Prussia, where there was a lack of hydropower, there were political advantages in favor of electrification.[58]

Such advantages were important because, as Walther Rathenau openly admitted in 1907, electricity had to be "forced on the consumer to a certain extent". "The countries that left this development to the consumer could only obtain such an economic structure imperfectly and second-hand." This is why "electricity in its current centralized form" actually originated in Germany. Here it happened that a district administrator
"defaulting" municipalities to connect to the electricity grid. The consequences of the newly strengthened intimacy between the state apparatus and the electrical industry were felt by the Berlin electrical workers in a surprising and unpleasant way during the strike of 1905, when the authorities took massive action to prevent the interruption of the electricity supply, which was now considered a public matter, at all costs during a sympathy strike by the machinists and stokers of the Berlin electricity works operated by AEG. During the First World War and in the post-war period, when the energy supply companies became state-owned or mixed-economy, "the political character of electrification became even more evident".[59]

The structure of the leading electricity companies, which was based on major state projects, was not necessarily conducive to creative and inventive involvement in the broad field of new electrically powered consumer goods - from radios to vacuum cleaners: the main thing here was to explore the market imaginatively and flexibly; no logic of systematic technical development provided information on how electrical engineering could best be marketed in the everyday life of the average consumer.[60] At times, it looked as if the Siemens-AEG duopoly would be overthrown by new companies. It was not only the mass production methods and service networks of large-scale industry, but also, time and again, major state or state-sponsored projects that consolidated the oligopolistic structure of the electrical industry.

However, the state's willingness to undertake large-scale electrical engineering projects reached its limits during the war and interwar period: this was particularly evident in the electrification of the railroads, which struck at the heart of the traditional domain of steam power. Werner von Siemens, who had the world's first electric locomotive built in 1879, was already
"Fire and flame for the idea of the electric railroad". Oskar von Miller, the most effective German advertising strategist for electricity at the time, also led a "campaign for the electrification of the railroads", and the issue of streetcars and the Berlin light rail system was brought to a head at the end of the 19th century.
19th century also went down well: At the time, the railroad business

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"overshadowed"

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Siemens "everything else". Despite the otherwise fierce competition, Siemens and AEG jointly founded the "Studiengesellschaft für elektrische Schnellbahnen" in 1899, and an electric railcar exceeded 200 km/h on a military test track as early as 1903, at a time when the top speeds of D-trains stagnated at 100 km/h. But the speed increase possible with electric locomotives left the German railway administration cold. But the speed increase possible with the electric locomotive left the German railroad administration cold at the time; the deterrent effect of the very high initial investment in systematic electrification of the railroad was all the more effective for a long time. Later, with the threat of air war, there were also military concerns about the vulnerability of the electrical systems, as well as autarkic worries about the high copper requirements of electrification. For a time, the diesel locomotive was considered to have a bright future; American railroads experienced a "diesel revolution" in the 1930s. Until the 1950s, the electrification of the German mainline railroads was limited to individual lines, and the supporters of the steam locomotive dominated the field. When electrification finally came on a broad front, the railroads built their own power stations.

As soon as the focus in engineering was on efficiency, the steam locomotive became an extremely imperfect design; its efficiency was difficult to increase beyond six percent, while stationary steam power plants in the 20th century reached 90 percent with turbines and waste heat utilization. The introduction of the steam turbine was also expected to be a "revolutionary development" for locomotives, but this proved to be a dead end. With higher pressures and steam temperatures and with cylinder compound systems, it was possible to increase efficiency by a few percent. North Germany was surpassed by France, which had less coal, and South Germany with the four-cylinder compound locomotive, the unpleasant maintenance of which the railroad staff in Prussia did not believe they could expect. However, efforts to improve the thermal efficiency of steam locomotives reached a limit in Germany around 1930. They overlapped with efforts to standardize locomotive design; however, the "standard locomotive" created in the 1920s did not become generally accepted.[61]

Under the competitive pressure of electricity, not only the steam,
but also further developed gas technology. The incandescent gas light, praised as an "ingenious invention" even by a partisan of electrical engineering, was brighter and more beautiful, even more economical, than traditional gas lighting, which appeared dull and bluish next to the sun-bright light bulb. In the mid-1990s, the German Gasglühlicht-AG became "the fairy-tale phantom in the German stock market sky", and the "furor electricus" (Riedler) suffered a setback. By 1900, the prosperity of the gas companies had come to an end.

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than that of the electricity plants, especially as the gas could be stored and the problem of even capacity utilization did not exist with the gas supply. In addition, the utilization of by-products at the gas works made great progress. In this situation, electricity often had a hard time at first. In Dortmund, where it had only taken three years from application to completion for the gasworks, the decision-making process for the first electricity plant dragged on for eleven years and only came to fruition around 1900: so little had electrification been regarded as the epitome of technical progress, even in the Ruhr region!

After 1900, however, discussions about the pros and cons of electricity soon became passé. After 1918 at the latest, when low-quality gas was supplied due to coal shortages, gas lighting experienced a "great catastrophe"; within a few years, gas was pushed out of its oldest area of application. But the battle for the much larger heating market, for stoves and heating, only really began at that time; it has not yet been decided. Gas, which made headlines as a terrible weapon of war, was considered more dangerous in households than electricity. The community of technicians who declared their support for gas could not be compared with the chorus of electric prophets.

The main obstacle to the gas industry was more sociological than technical; it also consisted in the fact that the gas works did not keep pace with the development of large interconnected systems due to their communal ties. From a purely technical point of view, it would have been possible to supply the whole of Germany with Ruhr gas; at times there were such plans in the Ruhr; but in the form of electricity, Ruhr coal had an easier time expanding. The *economies of scale* had a far more pronounced offensive effect on electricity than on gas. While industrial "power current" had just been propagated to fill the consumption "valleys" created by the mere flow of light, from the mid-twenties onwards, the full electrification of the household was promoted in order to compensate for the "valleys" created by the increase in industrial electricity consumption. The "first German electric housing estate" with a fully electrified kitchen was built in Schweinfurt-Schwandorf, albeit without convincing success. It was still generally perceived as wasteful to use electricity for anything more than lighting.[62] Different paths of technical progress were also recognizable in the private sector. However, these did not need to be understood as alternatives, but could also be pursued in a complementary manner.

Like the electricity supply, the *chemical industry* became a major player in the early 20th century.

It became a "national" matter in the 20th century. Like the electrical industry, it became an extremely concentrated sector and a key industry with seemingly unlimited potential for development and expansion.

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industry. However, the problem of forced technological development directions and the possibility of different paths also came to light here.

While the electrical industry had already come into close contact with government agencies through the telegraph business in its early days, the politicization of the chemical business took place abruptly during the First World War. At the outbreak of the war, the industry, whose export quota for paints was 82 percent, was still in a state of catastrophe; the BASF plant in Oppau had to close temporarily. For fear of administrative intervention, the dye companies initially refused to participate in the planned war chemicals company; in view of their exports, they would probably have preferred to remain neutral during the war. It was a dramatic turnaround when, shortly afterwards, chemicals became a key military industry and a saviour from shortages of explosives and fertilizers. Hermann Schmitz, who came from the Frankfurter Metallgesellschaft and was then a lieutenant and general representative of the War Ministry for chemical production, later rose to become Chairman of the Board of Management of IG Farben.

Although Heinrich Caro had already celebrated organic chemistry as an achievement of the "German spirit" in 1891 and proclaimed that "no branch of German technology" bore "with equal rights the name of a national industry", it was only after the First World War that chemistry could be regarded as a particularly "German" industry, both statistically and in an international comparison; in Italy, however, the share of chemistry in national industrial production rose even higher in the 1920s (1929: 13 percent; Germany: 12 percent). A leading German chemist at the turn of the century, such as Wilhelm Ostwald, was a pioneer of Esperanto and a sympathizer of the peace movement. Since the First World War, on the other hand, it was natural for a spokesperson for chemistry to be pronouncedly "national" - "national" in the sense of the word at the time, and even to such an extent that scientific exchange with France was not revived even during the Locarno period. This did not prevent merger negotiations between IG Farben and the new British chemical giant ICI from being conducted behind the scenes for a time.[63]

While synthetic chemistry had initially aimed to artificially produce substances that already existed in nature - whether indigo or ammonia - its ambition in the 20th century was increasingly directed towards the production of new substances that surpassed natural substances. This path, which had been followed so successfully with dyes, was theoretically unlimited; however, when it was pursued into new product areas in the early 20th century, it came up against cost limits and acceptance problems of a hitherto unknown magnitude.

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When new dyes were discovered, the excitement of the chemist in the laboratory seemed to automatically signal market opportunities. Formaldehyde was also regarded at the end of the 19th century as "one of the best examples of how a new reactive chemical substance very soon creates its own field of application, even if there is no such field to begin with".[64] However, the discrepancy between the scientific and technical appeal and the market value could not remain hidden in chemistry in the long term. When the chemical industry embarked on the path of large-scale technology and high-pressure processes during the First World War with the synthetic mass production of ammonia, sales were not yet a problem: the same product that was used to produce explosives during the war could be used as an artificial fertilizer in peacetime. However, when a technically related high-pressure process was used to produce synthetic fuel - the production of gasoline from coal using the hydrogenation process - IG Farben temporarily found itself in a critical situation.

At first, it looked as if fuel synthesis was bound to be a success in the short or long term. After 1918, Lord Curzon's statement that "the victor swam to victory on a sea of fuel" became a common saying in Germany. Yet the First World War only gave a faint foretaste of the enormous power-political significance of oil at a time of growing motorization. In such circumstances, in a country like Germany, which had little oil of its own but was the world leader in organic chemistry, was synthetic fuel production not the right way to go? In 1928, Julius Hirsch, former State Secretary in the Reich Ministry of Economics, described the artificial production of petrol as an element of "rationalization" par excellence. Around 1925, when the project was launched, the IG management does not seem to have speculated on a policy of armament and self-sufficiency; it was enough to believe in the unstoppable growth of automobilism, the limited nature of oil resources and the fundamental advantage of synthetic production. The world's oil reserves were vastly underestimated at the time; in the USA, too, people were impressed by IG's synthesis project, and Standard Oil was initially - but only temporarily - inclined to cooperate with the Germans in order to provide for the event of oil wells being exhausted.[65]

Nevertheless, the fuel hydrogenation project, the dimensions of which are already

The results were reminiscent of later nuclear technology projects, but there was no question of any real economic calculation. Although the chemical industry was already used to years of research and testing for the products of the dyes and pharmaceuticals division, high-pressure synthesis represented a quantum leap forward

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Figure 30: Joke card for a gentlemen's evening of leading IG Farben managers, 1941, alluding to the trademark of the Solingen cutlery company Henckels; the Henckels twins have become quadruplets here, and all together they are reminiscent of a ducat donkey. The newly founded plant near Auschwitz was intended to bind the Leuna works more closely to the Ludwigshafen parent company: The drawing and text also allude to this. Otto Ambros, on the far left among the "quadruplets", was head of the Buna factory near Auschwitz. Auschwitz only became an extermination camp in 1942; however, the IG plant was planned at this location with a view to the forced laborers available there. The joke card documents a mental isolation from the reasons for this project.

and a new style of technical development. This style was embodied by the group of chemists around Carl Bosch, who had been shaped by their work on ammonia synthesis during the World War and had gained an internationally unique wealth of experience through this; here, a new technology became group-forming and thus developed its own momentum. There was an alternative for producing gasoline from coal at a lower pressure: the Fischer-Tropsch process developed at the Mülheim Coal Research Institute. However, this had no large-scale industrial technology group of similar dynamism behind it and only reached a reasonable level of industrial maturity in the 1930s.

But even within the IG, Bosch had to push through gasoline hydrogenation as a new investment focus of corporate policy in the face of fierce resistance from Duisburg, which had to continue the older tradition of dye and pharmaceutical production.

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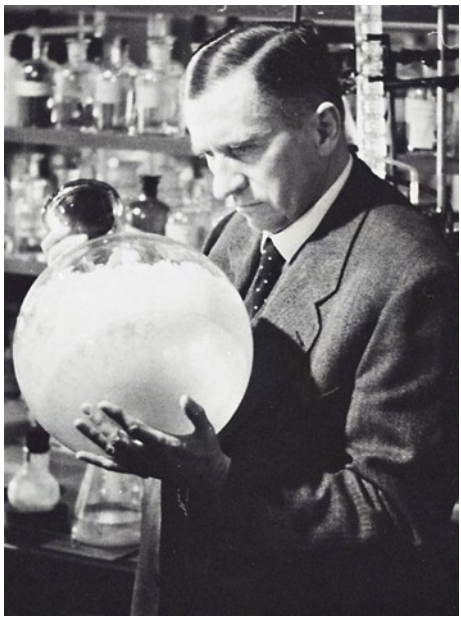

Figure 31: Carl Krauch (1887-1968), then Chairman of the Supervisory Board of IG-Farben and General Plenipotentiary for Special Issues in the Chemical Industry in the Four-Year Plan, in 1944. Although he had been a leading manager for many years and was now in a leading political position, he can still be photographed as a chemist in the laboratory: albeit with a large globe-like piston in his hand! Until the "economic miracle" era, the chemical industry was still dominated by chemists, not businessmen.

production and had still been able to make his own inventions "all at the laboratory table". The subsequent period proved the doubters right: from 1929 to 1931, the price of American export gasoline plummeted from eleven to five pfennigs per liter, while the IG's future plans had anticipated a liter price of 20 pfennigs.[66] The only hope for the hydrogenation project, in which the IG management - more out of a technicist than a business management mindset - had become entrenched, was a German autarky policy. It was on this basis that the cooperation between IG Farben and the NSDAP began and led to the chemical company, whose relationship with the NSDAP had originally not been good, ultimately being identified with the Nazi regime more than any other large company: not only with the National Socialist autarky policy, but also with Auschwitz.

At the same time as fuel hydrogenation, albeit initially at a much lower cost, the IG was working on rubber synthesis: this was also a speculation on a coming automobile age. The price of natural rubber also plummeted around 1930; in this case, the IG decided to largely discontinue development work. Here, the capital invested was not yet so high that it represented a psychological compulsion to continue. Even after 1933, the IG initially pursued a rather cautious tactic in the case of Kunstkau- tschuk (Buna) in the face of the impatience of the Nazi government and, unlike in the case of petrol hydrogenation, enjoyed the position of being able to continue production.

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who must be asked and pushed. Overall, however, IG invested larger sums in no other area during the Nazi era than in rubber synthesis. Buna production at Chemische Werke Hüls AG, founded by IG Farben in 1938, was technically doubly linked to petrol synthesis: The exhaust gases from the coal hydrogenation plants were the starting point for Buna production, which in turn produced hydrogen for the hydrogenation plants. After 1945, synthetic rubber became internationally competitive, albeit no longer by IG Farben. Although natural rubber, unlike crude oil, is a renewable raw material, the synthetic product gained a quality advantage over the natural substance. Wood saccharification, on the other hand, which Bergius, the inventor of coal hydrogenation, had been working on since the First World War and which had been operated on a large industrial scale in Mannheim-Rheinau with state support since 1928, sank back into insignificance, even though it was still a major part of the industry.

was at times celebrated as the path to a new "wooden age".[67]

In 1938, Claus Ungewitter, the head of the Chemistry Economic Group, expressed the conviction in connection with the aforementioned survey that the unpredictability of the future no longer applied to chemistry, and he justified this confidence with the scientific basis of this industrial sector: chemistry, said Ungewitter, would "follow the path shown to it by the research work being carried out today in universities and industrial laboratories".[68] This was the "philosophy" that suited long-term large-scale projects. But the predictability, insofar as it existed, was essentially that of *self-fulfilling prophecy*, which was guaranteed by the power of the prophet. The power concentrated in the IG, which enabled a technicist monomania in the pursuit of large-scale synthesis projects, could by no means be played out in all product areas of chemistry. Where success depended more on a flexible and imaginative response to changing and individual tastes and needs, the IG did not play a pioneering role and was dependent on purchasing innovations made elsewhere.

In 1913, Germany was the world's largest producer of artificial silk; in the twenties, however, it was overtaken by the Italian chemical industry. Characteristic of Carl Bosch's way of thinking is his decision in 1926 to remove coatings from the IG program, even though the IG coatings were selling well: coatings, Bosch said, were a purely empirical field and should be left to those companies that worked purely empirically.[69] In the same year, he bought the Vistra rayon factory in Premnitz, Brandenburg, which was only making losses and was on the verge of bankruptcy. Ten years later, in the wake of the National Socialist Four-Year Plan, Vistra was described by an effectively written book by Hans Dominik as a

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Germany's "white gold" and celebrated as the crowning glory of a history of textile fibers going back to prehistoric times. The share of rayon in German textile fiber consumption rose from 0.7 to 32.3 percent between 1933 and 1943, while that of cotton fell from 53.7 to 2.9 percent; Germany became the largest rayon producer in the world at the time. Perlon, the first fully synthetic fiber invented by IG in 1938, was more promising, while artificial silk and rayon with their cellulose content were only "semi-synthetic". Perlon was no longer a specifically German development, as nylon fiber was launched by DuPont at exactly the same time. In Germany, it was said that the nylon fiber was an accidental discovery, whereas Perlon was the result of systematic research. For Hoechst, however, the production of man-made fibers was still terra incognita in 1954.[70]

From today's perspective, the development of chemical synthesis and electrification, as well as the motorization still to be discussed, is of particular interest because it is the first time that the group-forming effect of new "cross-sectional technologies" and the emergence of scientific-technical communities can be traced with exemplary clarity: the formation of expert cartels that are capable of driving forward long-term and expansion-oriented technical developments, even through failures and lean periods, and securing the necessary political and public support. A technical guild had already developed around the steam engine; however, steam power only had a limited area of application, within which it long maintained an unrivaled position that required no special legitimization. The conditions for "expertise" in the 20th century style were not yet in place here, or only partially. No greater contrast is conceivable than that between the unfortunate List, who wanted to play the role of public advisor in railroad matters but was not needed by the interested parties enough to obtain the funds to pay off his growing mountain of debt, and, on the other hand, the triumphant Oskar von Miller, the "organizer and herald of the electricity propaganda", who also possessed the habitus of a smirking and rolling-eyed Bavarian original.[71]

By nature, engineers did not have a particularly strong esprit de corps. Several conditions favored the genesis of the new type of expert and its technical community: the emergence of "key technologies" that required teamwork and could gradually be applied to other areas, of procedural technologies with corresponding dynamics, fascination and integrative power; but also the existence of alternatives to be defended against and of situations where the community has the opportunity to form a common front and the aim is to secure the backing of major technical projects from political authorities and the public.

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opinion. The cohesion of these communities is not only created by technical problems and experiences. Rather, the technical "expert" is characterized in his role as political advisor by the fact that he uses supposedly technical logic to advocate positions whose justification exceeds the competence of the technician. The demand for a political leadership role for experts became a characteristic feature of the German technocracy movement. It coincided with the search of some politicians for a new guideline and source of authority in order to - in the words of Hilferding (1927) - "finally get out of political dilettantism".[72]

At a time when the synthetic product still had the aftertaste of "Replacement" and wartime hardship, Carl Bosch proclaimed a philosophy of eternal synthesis: "There is no natural substance that cannot be obtained synthetically. Yesterday it was dyes, today it is fertilizers, tomorrow it will be protein. Human nutrition will be revolutionized." The "Bosch School", a men's association in its purest form, was united not only by shared technical experience, but also by frustrations endured together and drowned in alcohol. During the war, IG Farben also sought to produce the new miracle drug penicillin - a natural substance produced by mold fungi - in a proven synthetic way; the advantage of biotechnology was initially not seen. Instead, the beer brewers of the Tyrolean village of Kundl, who had experience with fermentation processes, created a successful penicillin factory out of nothing after 1945: at a time when penicillin in Austria - as the film "The Third Man" - was practically only available on the black market.[73]

The "path dependency" of such production was rooted not so much in the technology itself as in the mentality of the *community* that had developed around a technological path - as soon as the advantage of biotechnology was clearly proven, German chemistry also adopted it without too much difficulty. The collective perseverance mentality developed in high-pressure synthesis most closely anticipates the mindset that later carried the breeder reactor project through ever new obstacles and disappointments. Just at a time when more and more alternative paths were becoming visible in technology, an offensive technological determinism hardened. In the rationalization publications of the 1920s, Brady found the stereotypical view, based on the authority of supposed science, that there was "a single best way".[74] Yet "rationalization" was one of the most ambiguous buzzwords of the time.

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4. Rationalization movement, psychotechnology and the "battle for the joy of work": the problem of adapting Taylorism and Fordism to German conditions

"Rationalization", assembly line work, the Taylor and Ford systems were fashionable topics and the focus of much discussion in Germany from 1918 until the Great Depression. Founded in 1921, the Reichskuratorium für Wirtschaftlich- keit (RKW, since 1949 the Rationalisierungskuratorium der Deutschen Wirtschaft in the Federal Republic of Germany) defined rationalization in 1927 as the "application of all means offered by technology and planned order to increase economic efficiency and thus to increase the production of goods, to make them cheaper and also to improve them". The short formula became even more popular:
"To rationalize means to design sensibly." Rationalization acts like a general economic reason that is independent of time and place, just like
"Rationalization" in the VDI declaration of 1988 ("Rationalization today") as a
"a general, reasonable human behavior and action" is defined.[75]

However, the rationalization that became fashionable in Germany after 1918 was shaped by the historical situation and the mood after the war and defeat. "Rationalization" seemed like a foreign word, but was, as the *Times* wrote in 1930, a "clumsy Germanic word" that originated in the post-war period. What the word meant in concrete terms could not be uniformly defined. One RKW man wrote in 1927 that the results of rationalization to date could not be precisely proven, but it was equally impossible to "stop" rationalization, whatever the result.[75] No wonder: above a certain level of complexity, corporate strategies elude exact calculation. In the era of fatalism, "rationalization" became a substitute for the old "progress". Max Weber, with his penchant for darker fatalism, had already prepared the career of this term before 1918, but at the same time emphasized its ambiguity and lack of value. This was forgotten by the rationalization prophets of the 1920s.

The rationalization processes of that time, which at the time were constantly justified by American models, were perceived as the strongest Americanization push in German history up to that point. As never before, there was reason to passionately debate the question of whether American production and lifestyles could be transferred to Germany and modified to suit German conditions or whether they should be rejected outright. Taylor and Ford, the authorities of the rationalizers, had nothing to do with each other as individuals; in Germany, however, they were seen partly as complementary and partly as contrasting principles. For Taylor, increasing productivity was a matter of improving human motivation and

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Work motorization, at Ford a matter of the technical system. Although Taylor had first made a name for himself as the inventor of high-speed steel, which increased the degree of mechanization in mechanical engineering, he demonstrated his
"system" in very simple manual work such as loading iron parts, which would have tempted a Ford to mechanize immediately. Taylor therefore seemed less "modern" than Ford; on the other hand, he took account of the fact that even highly mechanized work processes still involved a great deal of human manual labour, a fact that had been neglected by engineers until then. To conceive of man as a mechanism to be increased to optimum efficiency: That was the pinnacle of mechanization, assuming that humans could not be eliminated from the production process anyway.

In practice, "Taylorism" was often equated with time studies, which determined the duration of a work process with an optimal sequence of movements and made it the norm. In the USA, Taylor's "scientific management" was mainly used pragmatically as a method of work organization after 1918, whereas in Germany, in the situation after the end of the war, it was preferably elevated to a company social philosophy: a philosophy of economical use of the most precious resource, people, and a guide to internal harmony, in which the determination of workloads and wages was seemingly objectified and the arbitrariness of masters was replaced by factual logic.[76]

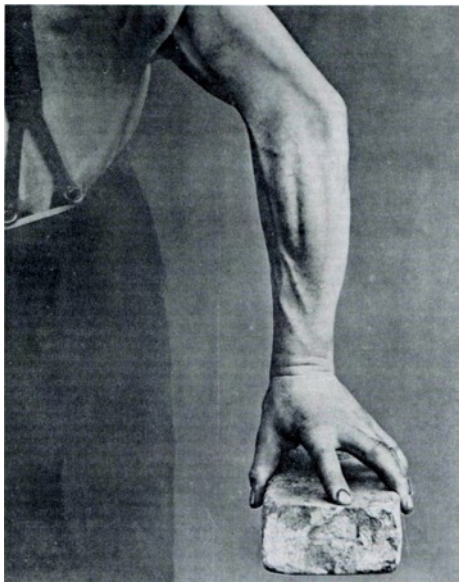

Figure 32: The photo from 1926 shows a bricklayer gripping the stone in the clamping grip and tensing his arm muscles. At that time, labor scientists demanded that not only the mechanics of the machines, but also those of the human body be investigated, in this case: to determine exactly up to which stone format this gripping method can be maintained with one hand in the long term and when the bricklayer has to grip with both hands. The new methods developed in the course of "Taylorism" and
"psychotechnology" of the 1920s had an ambivalence between humanization and increased control of work.

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"Fordism" was generally equated with a perfect assembly line system, with mass and serial production on a grand scale, with the reconciliation of capital and labor on the part of entrepreneurs, and with maximum wages on the part of the trade unions. While the slogan in the workers' movement before 1914 was *"piecework is murder!"*, the piecework system was increasingly accepted by workers after 1918 if it led to higher wages. While Taylorism, which - when practised consistently - meant the complete planning and control of work through work offices, worked towards bureaucratization and a strengthening of middle management, Ford's teachings bore the signature of the technocratic entrepreneur, who abhorred all bureaucratic intermediaries and any kind of paperwork and wanted the production process to regulate itself through flow work.

While Taylor was discussed in German circles before 1914, Ford's impact began around 1924, when the German edition of his book *Mein Leben und Werk* was published and Germany was opened up to American credit and automobiles. Ford's book, which was followed by two sequels, seems to have made a greater impression in Germany than in the USA, even though very few Germans could afford a Ford car. Ford, who was already well remembered by many Germans as a campaigner against American intervention in the First World War, became much more popular in Germany than Taylor, and his popularity ranged from the General German Trade Union Confederation (ADGB) to the NSDAP. With brash self-confidence and in an aggressively cheerful style, Ford and his ghostwriter proclaimed the gospel of unlimited prosperity through tireless rationalization of the production process. In Germany's post-war misery, Ford's visions acted like a drug that transported Germans back to the euphoria of Wilhelmine times, to the mood of unlimited possibilities and "full steam ahead".

The rather alienating features of Ford's doctrine for many Germans - the contempt for tradition and formal qualifications - were preferably overlooked. A German engineer wrote after a trip to the USA,
"Every company man" should "make a pilgrimage to the Ford factories, like the believer to the tomb of the prophet in Mecca". Ford's teachings were "virtually a revelation and a release from an uncanny pressure weighing us down in Germany". Louis Betz, a passionate propagandist of the "people's car" idea, glorified Ford even at the height of the economic crisis as a
"outstanding genius", who could also become an "outstanding leader" for Germany: "Ford's plans are our plans. Ford's victory is our salvation." The same author had already warned in 1928 that a "blind imitation of American assembly line methods in our German automobile industry would not be a good idea".

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nissen" was "completely impossible". For many German Ford enthusiasts, Ford was much more than just the assembly line system; he embodied the conviction that there was a technical solution to all problems if one was only ruthlessly determined.[77]

Whereas in the traditional German view, which persisted in the 1920s, the USA had been the land of wastefulness and shirt-sleeved pragmatism, while Germany was the land of frugal housekeeping and scientific technology, there was now a new kind of reception of American production methods: Taylor and Ford had the effect on German admirers of synthesizing the Germanic and the American by elevating the strict economic handling of production factors and the systematic planning of the production process to a principle. Taylor's model worker was a Pennsylvanian-German, whom he named "Schmidt" in the *Principles of Scientific Management.* Mass production and precision, two previously contradictory ideals, seemed to become one technical unit at Ford.

With Taylor's "scientific" management, the irritating word "scientific", which until then had mainly radiated from Germany in technology, returned to Germany in an American guise. It was only occasionally noted that Taylor was not a "scientist" in the German sense, because Taylor's method of determining the optimal working technique consisted of observing experienced and highly motivated workers, for whose traditional skills and knowledge he had great respect. Strictly speaking, he did not replace work experience with science, but rather one experience with another. For Taylor and Ford, as well as for the German spokesmen of rationalization, "science" had not least a legitimizing function. With reference to "scientific methods", Ford justified the fact that his machines were "more closely aligned" "than in any other factory in the world". Berlin city planning officer Martin Wagner, a protagonist of "Fordism" in urban planning, had old buildings ruthlessly renovated in the name of "scientific urban planning".[78]

The invocation of American role models also had legitimizing value in Germany after 1918 as well as after 1945, because the USA never seemed as fascinating as it did in post-war Germany. Before 1914, American authorities were not necessarily a trump card in Germany. In 1913, Bosch's management had to defend itself against the accusation that "Taylor was master at Bosch"; although Bosch was more popular with the trade unions than with fellow entrepreneurs, company reorganizations in the Taylorist sense were one of the triggers of a sensational strike. After 1918, however, the general mood had changed, even among the SPD and trade unions. Taylor and Ford were now able to

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The "Americanization" of the 1920s can be interpreted to a large extent as a forced continuation of tendencies towards standardization, standardized mass production and "large-scale economy", which had been given a strong boost by the First World War, but needed a new civilian basis after the end of the war.

Until 1914, German industry had lagged behind the British in *standardization* and the Deutscher Werkbund had almost collapsed over the issue of standardization. After the war, such issues were no longer fundamental questions. Instead, standardization was at the heart of what German business and technical circles called "rationalization" from the very beginning. The USA was always cited as a model for standardization and typification; in reality, however, the national standards system established by the "Standards Committee of German Industry" founded in 1917 represented an internationally unusual generalization of the standards principle at the time. Ford himself was content with internal standardization; he was generally opposed to the long-term establishment of standards and warned that it was "considerably easier to set up a wrong standard than a right one".

In Germany, standardization was often presented as an imperative of simple technical reason, even as a "logical product of the common human urge for order", and in the classic standardization case of screws and threads it was; but in many other cases, the setting of standards was based on arbitrariness that benefited powerful corporate interests while thwarting other interests. Technical innovations could be hampered by standards, and export opportunities in regions where other standards were common could also be impaired. A fixed system of standards provided export advantages, especially for industries such as mechanical engineering, which were in a position to dominate foreign markets. After the end of the war, when standards could no longer be imposed on companies, German industry - in the view of one DIN supporter - "sank back into its old ways". Rationalization here meant reactivating the order achieved under the pressure of war. The self-will of the private entrepreneurs was tenacious and repeatedly asserted itself. As late as 1930, DIN standards were often ignored in industry; it was not until 1936, during the Four-Year Plan, that standards were made mandatory by the Reich Ministry of Economics. But even during the Second World War, type production was still the thorniest problem in German aircraft construction. In the 1920s - as an article in the *Weltbühne* revealed - "failed series production" at the Junkers aircraft factories had wasted "insane sums".[80]

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In Germany, as in other European countries, Taylorism served in part as a contemporary justification for an older tendency towards the bureaucratization of companies and the displacement of "master control" by expanding management. In parts of the electrical and mechanical engineering industry, time studies had already been carried out before 1914: but the "whole time study movement" had a "very bad reputation" in Germany and was regarded as an outgrowth of American agitation and the hunt for the dollar. In Germany, the recipe of "Fordism" was able to build on existing traditions of series and mass production, for example in the bicycle and sewing machine industries. In the machine tool and car industry, this meant "series" a much smaller quantity than in the USA; but this was rational in terms of German market conditions.[81]

Was it true what was sometimes emphasized: that the ideas of Taylor and Ford, and rationalization in general, were actually nothing new in Germany? In Germany before 1914, however, all of the above were rather sporadic and gradual processes that were not necessarily widely publicized. In the 1920s, on the other hand, all these approaches to rationalization presented themselves as a bundled and systematized overall process and as an application of American recipes for success, both for the public and for the employees in the companies. The national economist Moritz Julius Bonn remarked in 1928:

"In the past, individuals used to reorganize their companies without being heard much about it, if the market situation required it and if their financial situation allowed it. Today, rationalization is carried out by groups; sometimes you only hear the noise and see little of the rationalization."

The buzzword "rationalization" was able to send "broad sections of the German people" into a "frenzy of enthusiasm". Rationalization" even provided the basis for a basic consensus between big industry and the trade unions! At a time when the new technology was increasingly taking the form of a process that reached all parts of society, this public climate was not unimportant. Time studies were no longer as disreputable as they used to be when, from 1924 onwards, the REFA (Reichsausschuß für Arbeitszeitermittlung - Reich Committee for the Determination of Working Time), which was founded at the time, made them a national task with a kind of scientific system, with which - as the REFA association proudly announced - Germany even surpassed the USA. The determination of fair wages became a technical problem in the REFA doctrine. The trend of large-scale industry towards American dimensions, at the beginning of the century a symptom of megalomania for a large part of the public, became an imperative of technical rationality under Ford's sign.[82]

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Technology itself became an ideological abstraction. The technical aspect of rationalization was emphasized with particular preference, as this was the most popular part of rationalization. In retrospect, this led to the strange distribution of roles, with trade unionists and even communists, who otherwise attacked the exploitative character of rationalization most vehemently, accusing entrepreneurs of neglecting the technical side of rationalization. In fact, rationalization in industrial practice, especially in the first years after 1918, often served as a method to increase productivity without costly new investments: through tighter organization, cost-cutting measures and intensification of work. Ludwig Preller, one of the best experts on the working world of the time, saw the fixation of company management on new
"technical miracle" was more a relic of the pre-war period, while the discovery that the "human factor of production" was also worthy of "rational design" characterized the post-war period. During the global economic crisis, however, there were complaints that rationalization had been understood too unilaterally in technicist terms and equated too much with the assembly line.[83]

During the rationalization movement of the 1920s, the public debate took on a life of its own. As with the "new technologies" of the present day, the noisier part of which is implemented via politics and the public sphere, it is not always easy to identify the real history behind the history of discourse. What did
"Rationalization", "Taylorism", "flow work" in practice? The Taylor system was probably only rarely practised in its entirety - as the planning and definition of every work step and work process by corresponding offices - even less so in Germany than in the USA. It contradicted the traditions with which German industry had been successful on the global market and continued to be so. Wherever small series and diverse production programs prevailed, a rigid separation of planning and execution made no sense. REFA people who wanted to reorganize production had to deal with the foremen; and some of them preferred not to get involved at all. Even after the introduction of REFA studies, the determination of the work process often remained the responsibility of the foreman. Even in the 1950s, there were still complaints that "a great many REFA men" assumed that the work process was "perfect" in its existing form, and that in "many" companies "the sequence of work and the working method were left to the workers themselves", so that a certain
"style" of work that was very tenacious. A production theory based on observations of practice in a wide range of industries (1946)

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recognizes a dialectic back and forth in the external control of industrial work:

"In contrast to Taylor, the general view today is that the distribution of work is fundamentally a matter for the master. [...] A period in which the master was given too much responsibility was followed by a period in which he was given no influence at all and therefore no authority. Today, efforts are being made to restore his natural rights. "[84]

What "rationalization" meant in concrete terms and with priority differed from industry to industry. In heavy industry after 1918, the heating industry and the technical integration required by the use of blast furnaces and coke oven gas were the top priorities. Rationalization in the chemical industry meant, as the Enquete Committee of the Reichstag stated, above all "rationalization of corporate structures", primarily through concentration. At Bosch, where the nature of the products already allowed for forms of series production before 1914, rationalization meant assembly line production, but not continuous assembly line work and no systematic mechanization of previous manual work; this would have contradicted the production of rapidly changing small series of detonators, which was forced by the change in car models. The most remarkable aspect of this rationalization was the space saving of 70 percent. In the case of German machine tools, as was noted in 1932, the "special machine of the highest level of development", which was specialized in a single production process and a single product and corresponded to the ideal of perfect "Fordism", was rare, as it did not allow for flexible product diversity.[85]

The first assembly line was used as early as 1905 in the Bahlsen cookie factory in Hanover; however, the introduction of the assembly line only became a technically revolutionary process in the manufacture of highly complex products, where assembly line work broke through a developed workshop system and required the combination of a large number of special machines. From the early days to the present day, the assembly line has therefore been particularly exciting and sensational in the automotive industry, where the manufacture and assembly of thousands of individual parts had to be organized as an interlocking sequence. Nowhere else in interwar Germany, however - despite the enthusiasm for Ford - was the introduction of the assembly line as difficult and controversial as there. The self-will of the designers, the narrowness of the market and the demands of the German customers of the time, which seemed difficult to satisfy with a uniform mass product, all worked together. Or were the car manufacturers, accustomed to their heavy cars and wealthy buyers, just imagining that there was no market for a light and cheap mass product in Germany; were they not bold and inventive?

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Figure 33: Gearbox assembly at Daimler around 1927. The photo reveals more clearly than
"Fordist" hymns of praise at the time that the Ford assembly line was only introduced on "islands" in the German automotive industry, which produced much smaller series than Detroit, if at all. Here in the foreground is one such "Fordist island"; at the back left is old-style workshop production. Even in technically new industries, manufactory-style production methods, in which the workshops were teeming with people, prevailed well into the 20th century.

rical enough to create such a market? That was the big question that remained unanswered in the twenties.

Daimler, which began to introduce so-called group production as a preliminary stage of assembly line production after 1918, still did not build as many cars in 1921 as Ford did in a single day. The advance of the stockbroker Jakob Schapiro, who brought 40 percent of Daimler's share capital under his control in 1924 and publicly called on the company management to switch to assembly line and mass production, was fended off with the help of Deutsche Bank and branded a Jewish intrigue by ethnic nationalists. Even the merger of Daimler and Benz (1926) was not associated with a reduction in the number of models; on the contrary, the product range was broadened. Even the "Auto-Union", to which four Saxon automobile manufacturers joined forces in 1932, refrained from drastically reducing the variety of models. However, as Rainer Flik sums up, it was precisely this highly unsatisfactory development for Ford fans that ultimately turned into an evolutionary success story, which gave rise to the "Beetle" that conquered

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"Under the selective pressure of the crisis, there was a race for product innovations, from which a compact small car type with excellent driving characteristics and low fuel consumption gradually emerged. The astonishing result was that the fragmented, unprofitable and highly indebted German automotive industry made the most significant contribution to the further development of motor vehicle technology."

The Opel company was particularly early to introduce the assembly line (in factory jargon: "jazz line"), which had already gained experience with assembly line work in the mass production of bicycles and - located in the occupied Rhineland - had to assert itself against French and American competition immediately after 1918 without customs protection. Nevertheless, contrary to the public impression, car production in the 1920s never took place on a continuously running assembly line; instead, there were a large number of individual lines whose speed was set by the foreman. The increased production capacity was never even close to being fully utilized; production fluctuated greatly from month to month, contradicting the steady flow of production that the assembly line aimed to achieve. The production of interchangeable individual parts was not introduced at Opel in the 1920s; qualified skilled labor was still indispensable for the "fit". Since wages for automobiles accounted for only a tenth of manufacturing costs, there was no great incentive to save on skilled labor in assembly. In the German automotive industry of the 1950s, the interchangeability of parts was still managed by skilled grinders; it was not until the 1960s that Ford's level of mechanization was reached - only to be recognized soon afterwards as questionable progress that led to production bypassing the market.[86]

Even if the plant managers and engineers who introduced assembly line work were the first to make the pilgrimage to America in the 1920s, references to the need to adapt American models of rationalization to German conditions were part of the permanent repertoire of relevant journalism from the very beginning. In the German automotive industry in particular, there was every reason to emphasize the necessity of limiting production to small series due to the German market; after all, Ford's fascination was a constant reproach for this industry. But if in 1915 the Daimler director Berge had still spoken of a "German system" of automobile production that was superior to American mass and cheap production, this self-confidence had taken a strong hit in the 1920s despite the brashly nationalistic tones of German automobile propaganda: German small-series production was increasingly regarded as an incomplete preliminary stage of Fordism, corresponding to a poorer country where the car was still a privilege of the upper classes. In conservative circles, the old motto of "quality versus quantity" or its newer variant "quality versus quantity" was still

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ante "class instead of mass", progressive concepts of motorization without mass production according to Ford's method were still lacking. Even the end of Ford's T model (1927) was not generally perceived as an indication of the fundamental weaknesses of rigid mass production. Only Ford himself subsequently turned to nostalgia, to "European" models and to praise of decentralization and the "new craftsmanship".[87]

In a continuous assembly line system, the worker hardly had any direct positive influence on his performance, but could only disrupt the production flow by working more slowly; performance-based wage differentiation was hardly possible under such circumstances. In 1928, the Reich Labor Court ruled that only time-based wages were permissible for work on an automated production line. However, the flow system was generally not implemented so consistently; a "crisis of performance pay" existed only temporarily, at least in terms of the technology of the production process, and the prediction that the development of production techniques would undermine individual or group-based performance pay in the long term had not yet been fulfilled in the 1970s.[88]

From a purely technical point of view, rationalization - as a study by the German Metalworkers' Association noted in 1932 - should have significantly reduced the frequency of accidents: through the increased order in the factory halls, also from the outside, the mechanization of transport, which until then had been one of the worst accident areas, and the replacement of the dangerous transmission belts by the individual electric drive. However, the reality was often very different: The aforementioned "rationalizations" were generally only partial and were associated with increases in the pace of work. In the iron, machinery and automotive industries in particular, rationalization in the second half of the 1920s led to a marked increase in accident frequency. At Bosch, which was proud of its low accident rate before 1914, the frequency of accidents had risen no less than 25-fold by 1928, when the "Bosch pace" had become proverbial (68 injuries per 1,000 employees annually compared to an average of 2.76 in the years from 1909 to 1918)! In the ready-to-wear and lingerie industry, the electric sewing machine drive did indeed eliminate the "trampling" that had led to abdominal illnesses among the workers; however, the simultaneously increased number of tours worsened the state of health in the "rationalized" factories.[89] In practice, rationalization was not a "clean" process guided by higher reason; the advantages of the clearer order were overcompensated by greater confinement and higher speed.

In the German rationalization literature, it was repeatedly emphasized that "flow work" is a multi-level and adaptable structure.

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which should not necessarily be equated with the assembly line and the procurement of new, highly specialized machines, but on the contrary could bring about savings by accelerating the turnover of capital. Under German conditions - concludes a book on assembly line work published in 1926 - "the principle of assembly line work should initially [...] be transferred to a mental conveyor belt in order to achieve a partial success first - increasing the speed of work, reducing capital requirements and production costs - with cheap organizational measures".[90] But perfect assembly line production remained the ideal; and during the global economic crisis it became apparent that the switch to capital-intensive forms of assembly line production had been pursued to an extent that far exceeded Germany's sales potential. When flow production was consistently mechanized, a technological chain reaction with ever new investment incentives arose. The national economist Eugen Schmalenbach, an expert on numerous rationalization projects at the time, remarked in 1928:

"In countless general meetings, one hears the management say that the company is not yet working fully satisfactorily; but if a few more machines are purchased and other expansions made, then the company will become profitable. But since other companies in the same sector are doing the same, the industries automatically rationalize themselves into an oversized capacity. "[91]

The problem was thus seen even before the global economic crisis; what was typically missing was the insight that the combination of manual labour and mechanization, of workshop and limited flow production could not only be an imperfect and provisional compromise, but an optimal production method of its own kind. For all its German nationalism, the "German production regime" - to use Werner Abelshauser's term - was strangely lacking in self-awareness and self-confidence. Although practice in many German companies was always characterized by a high degree of flexibility, it was only in the 1980s that people learned to turn this flexibility into a system with its own optimization methods; a great deal of rigid hierarchical and orderly thinking had to be overcome before this insight was gained. The actually banal insight that it is not important to produce as much as possible as quickly as possible, but rather to produce the right thing at the right time, became the new Japanese revelation as the "just-in-time philosophy". Instead of rigid technical networking, a regional "cluster" of supplier companies now became the trump card: a model that had long existed in Germany without the corresponding theory.

While industry used to emphasize that Germany was not America and that the Taylor or Ford system could not be completely adopted, in plain language this always meant first and foremost that the highest wages in the US should be paid in Germany.

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German entrepreneurs could not be expected to pay. When Ford installed his first assembly line in Berlin in 1926, he offered an hourly wage of three Reichsmarks, which even engineers in Germany at the time would work for. Not least because German industrialists were unwilling and unable to pay Ford's wages, Ford and Taylor were accused of baiting workers with naked materialism without worrying about how to make the work itself satisfying. Wages were precisely the reason why leading German trade unions were enthusiastic about Fordism, although Ford's fiercely negative attitude towards the trade unions must have been well known. Ford's book *My Life and Work* contained key sentences such as this: "The wage question eliminates nine tenths of the psychological questions, and construction technology solves the rest."

The neglect of all psychology was a standard accusation in German literature against Taylor's regimentation of labor and Ford's assembly line. *"Psychotechnology"* became a typical buzzword of the German rationalization movement at the end of the First World War. The modern engineer should be trained in industrial psychology. Georg Schlesinger, who had become increasingly focused on technical aspects of humans and human-technology hybrids as a result of the war-related work on scientific prosthesis technology, founded an "Institute for Psychotechnology" in Charlottenburg in 1918. The establishment of "psychotechnical" lectureships and institutes subsequently became a formal fad at technical universities, although their practical value remained highly doubtful. "Psychotechnology" - the term itself an indication of the appeal of "technology" at the time - primarily meant the development of aptitude tests that met the specific requirements of certain jobs. Another focus of the emerging work psychology was fatigue: another blind spot of Taylorism and Fordism.[92]

Some of the German spokespeople for rationalization explicitly rejected the tendency to devalue skilled workers contained in the teachings of Taylor and Ford. The German tradition of valuing skilled labour was continued in the rhetoric of the rationalization movement. The "Dinta" (German Institute for Technical Work Training), which was founded by heavy industry in 1925 and aimed to bring vocational training entirely under industrial control and to provide training and "personality development" for an elite of young workers in line with the requirements of heavy industrial rationalization, combined this with a romantically tinged indoctrination in the spirit of the "factory community" and became a model of National Socialist workers' education policy.[93]

Nevertheless, it would not be right to see the "battle for the joy of work" proclaimed by parts of the rationalization movement as merely an ideological

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maneuver to distract attention from the wage issue. There is no doubt that many studies on work satisfaction were meant seriously and were not mere business propaganda. There was a reason why "work satisfaction" became the favorite topic of German labor science. Under the conditions of flexible small-batch and one-off production, there was actually a much greater need for a skilled workforce that identified with its work than with Ford's production method, which tolerated an enormous fluctuation of employees. A pronounced emotional identification with the work - "joy" was probably too euphoric a term for this! - was most likely to be found among skilled workers; their dominance in the factories was also
"rationalization" of the 1920s was not seriously shaken. The "fight" had to be for the "joy of work", primarily among unskilled workers.

In German industry, some traditionally versatile and manual occupations such as the lathe operator felt the de-skilling effect of rationalization, but overall the de-skilling effect of the rationalization processes in the 1920s was not very noticeable.[94] Rationalization even partly favoured the emergence of new elites of skilled workers, who also strongly influenced the formation of opinion in the trade union leaderships: this also explains the trade unions' friendliness towards rationalization. Even for pieceworkers striving for the highest possible earnings, a limited amount of flow work was beneficial, as the flow of work reduced the waiting and standing around that was part of everyday life in the workshop system and cost wage deductions.[95]

The German *struggle for the joy of work* - the title of a book published in 1927 by the Belgian socialist Hendrik de Man, who was appointed to the newly created Chair of Social Psychology at the University of Frankfurt in 1929 - had no basis in an alternative concept of industrial progress that could have been contrasted with the ideal of fully mechanized mass production; and this lack of perspective dampened the joy of work even where relatively autonomous forms of skilled labour still existed. The model of job satisfaction through semi-autonomous group work - where the assembly line was replaced by swiveling assembly stands - had to be re-imported to Germany from the USA and Sweden (Volvo!) much later. The traditional Solingen cutlery industry experienced a new heyday in the 1920s, thanks in particular to its rich product range; and yet the Solingen cutters fatalistically expected the demise of their trade. During the global economic crisis, many unemployed people cursed the machines that made people jobless; bourgeois and socialist economists, however, taught that it was not rationalization as such, but the inconsistent use of the machines that was to blame.

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or misunderstood rationalization ("misrationalization") was to blame for the crisis. The idea of permanent unemployment caused by technology only emerged in the margins of economics, for example in Emil Lederer, who in 1931 declared "the social restraint of technological development to be a vital issue for European nations". Later, in exile in America, he refrained from such consistency.

The way out of the basic dilemma of rationalization based on the American model, but under much more limited conditions, could instead be sought in the political creation of a large area adapted to the large production systems. Ernst von Streeruwitz, the founder and head of the Austrian "Kuratorium für Wirtschaftlichkeit" and temporary Austrian Chancellor, published a 540-page opus *Ratio- nalisierung und Weltwirtschaft* in 1931, in which he proclaimed a redistribution of the "living space on the whole earth" as a "very great and genuine rationalization".[96] Not without intellectual consequence, the demand for expansion became the ultima ratio of rationalization driven into a corner.

Was there also a fundamental criticism of the world view of "rationalization"? Ernst Poensgen, the deputy general director of the Stahlverein, who had seriously overreached himself with his rationalization measures, was furious at the mere mention of the word "science" in 1931:

"Leave me alone with science! We have been fed and overfed with science, scientific technology, scientific management, scientific materials science, scientific market research, scientific accounting, and so on and so forth. And where has all this science got us?"

The global economic crisis reinforced the experience that company strategy must first and foremost not be oriented towards the highest perfection of the production system, but towards flexible interaction with the market. This pragmatism - postponed by the Nazi dictatorship - became the prevailing attitude in West Germany after 1945. It was the antithesis of the productivist aversion to trade, which is expressed in Rathenau's almost disgusted remark about the situation where "tens of thousands of able-bodied men lurk behind store counters in a large city". However, the Nazi state, which erected a monument to Rathenau's murderers, gave new security to productivism, which had been shaken by the crisis.[97] In its own way, National Socialism was also - partly directly, partly as a counter-reaction - a successor to rationalization.

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5. Energetic imperative, economy of blast furnace gases and large-scale technology

In its final report in 1930, the Reichstag Committee of Inquiry "to investigate the production and sales conditions of the German economy" noted that "the fundamental aim of concentration is the rationalization of companies on the technical and commercial side". In Germany at the time, "rationalization" was much more strongly associated with concentration than in the USA. In historical reality, rationalization in the sense of the most effective use of production factors could therefore hardly be separated from economic concentration, centralization of energy supply and large-scale technology. In the early 20th century, orders of magnitude were reached that represented a clear leap beyond the dimensions of the late 19th century. Even if this drive for size did not always follow a technical logic, it still corresponded - as Riedler emphatically emphasized - to the interests of the engineers who were fighting to overthrow the "master rule" in the companies. According to Riedler in 1916 - who had the new power plant headquarters in mind - "everything essential [...] becomes engineering work" in the "large-scale economy", namely "through the deepening of shared work and also the generous organization of progress":

"The engineering activity in the large-scale economy offers an almost unlimited expansion due to the diversity of applications, the constant need for new designs and the difficulties to be overcome, which cannot be mastered with the traditional partial experience."

The words were spoken during the war, when the pathos of greatness was in the air anyway and the need to save resources was naturally associated with large-scale organization and large-scale technology. But this constellation was not created by the war; it was only stabilized by it.

Once again, the period around the turn of the century and thereafter appears to be a formative phase. The realization that everything in industry and life is ultimately energy and that all art consists in managing this energy came over the chemist Wilhelm Ostwald one spring morning in the 1990s like "a true Pentecost, an outpouring of the spirit". He rightly assumed that the full consequences of the entropy theorem, which meant the decrease in usable energy in all energy conversion processes, had not yet been understood. His *"energetic imperative"* initially *seemed* strange to his contemporaries, but later became a household word. Even Taylor referred to him, because Ostwald, who felt encouraged by his own psychosomatic collapse to seek his mission in "energetics", wanted to apply the doctrine of economical energy management to humans as well.[98] The philosophical trait

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of his doctrine was based on the fact that he saw the

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physical concept of energy with the other, older concept of "energy" as human energy.

Around 1900, when the "coal emergency" alarm sounded at times, "energetics" became increasingly popular. Until then, the main focus of technicians had been on the functionality of the machines, but in the following years the focus shifted to optimum efficiency. In the 1890s, four-fifths or even more of the energy produced was still being wasted in the mining and smelting works, and this "wretched state of affairs", according to Riedler, was not even known to most plant managers; most other companies were also unaware of their specific energy costs. Rising coal prices, growing competition and advances in engineering science brought about a change in attitude, and not only towards drive and thermal energy. Fritz Neuhaus, General Director of Borsigwerke and a champion of standardization and Taylorism, announced at the VDI Annual General Meeting in 1913 that the nation "which makes the best use of its treasures and resources" and brings them "to the highest level of efficiency" would "gain a wide lead over others".

The post-war emergency gave such wisdom a new relevance. "The time of unobjectionable economic activity with the energy sources and material stores that nature has made available to us will probably only have the significance of a past economic epoch for our children," wrote the physicist Walter Schottky in 1929: a very premature prediction, as we know today. "Think in terms of efficiency" - as the Austrian socialist Otto Bauer put it in 1931 - was the "watchword of the time". The "energetic way of thinking" characterized the "age of long-distance power plants and high-voltage lines, high-pressure steam and giant turbines, combustion engines and the heat economy". Technocratic doctrines culminated in the demand for an "energy currency".[99]

Immediately after the war, the focus of rationalization was entirely on economy, especially the economical use of coal, which had become scarce due to the reparation obligations and the losses in the Saar region and Upper Silesia. *"Heat economy"* was the slogan which, according to a speaker at the newly founded Association of the German Steam Boiler and Apparatus Industry, "sank into the people's soul". At the beginning of 1920, the VDI, the Vereinigung der Elektrizitätswerke and the Verein deutscher Eisenhüttenleute jointly founded the Hauptstelle für Wärmewirtschaft, which was dedicated to the dissemination of technical knowledge for the "better utilization of fuels", primarily in heavy industry, but also in other branches of industry. "Heating centers" were also established within industrial companies at the time.

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Several partly parallel, partly competing ways out of the shortage were emerging: in southern Germany, large-scale development of hydropower, "white coal" - in the north, a critical
"hydropower frenzy" -, in Saxony and in the left Lower Rhine region the large-scale open-cast lignite mining, on the Ruhr the better utilization of lower coal qualities and the blast furnace and coke oven gases and everywhere the improvement of the thermal efficiency in the technical plants. Walther Rathenau remarked in 1920 with emphasized acuity:

"We believed that our technical level of machinery, our power and work machines could hardly be surpassed, and yet, if you drive around the country, you will find power machines that are so lacking in economy that more frequent use must simply be described as criminal. "[100]

The improvement of the heat economy, consistently pursued in all directions, was a never-ending process. In 1925, when coal shortages were no longer a problem, a "fairly sharp" distinction was made between a "low" and a "high" heat economy.
"high school" of heat management and said of the latter: "The heat engineer should not just be a calorie catcher, but should look beyond the immediate boundaries of his field, as there is sometimes much more to be gained here than from fuel savings." The main focus here was on "coupled processes", the use of existing waste heat and exhaust gases. In 1925, Christoph Eberle, the head of the main office for the heating industry, proclaimed: "There is hardly a time in our heating technology that was richer in new possibilities than today." You can see how a technical community developed around the heating industry at times, but how the goal shifted from actual economy to an expansive increase in efficiency. A real increase in productivity aimed at savings should have been limited to those technical strategies that did not simultaneously require an increase in production complexes; under the conditions of the time, however, the heating industry was caught up in the maelstrom of the *economies of scale*. After all, heavy industry was the mainstay; and from 1924, after the end of the Ruhr War, the problem in the Ruhr was no longer coal shortages, but an oversupply of coal. In addition, the large influx of American loans began at that time.[101]

From a purely technical point of view, there is actually a smooth transition between saving and scaling up measures, as heat losses can be reduced by enlarging the steam boilers, increasing the pressure and combining several production processes. The entire process therefore exemplifies the problem of saving resources from a purely technical point of view and linked to industrial ambitions; something similar has been repeated several times in history. In the late 18th and early 19th centuries, the centuries-long efforts to save wood turned into a kind of

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The increase in efficiency was linked to an increase in the size of production facilities. The "thermodynamic religion" around 1900 (Eugen Diesel) provided the background music for a stormy large-scale industrial expansion. In the 1930s, the National Socialist policy of self-sufficiency, far removed from real self-sufficiency, helped to increase the pressure for expansion. After the Second World War, saving coal once again became a technical and economic imperative, and once again we can see how saving led to expansionary strategies, although this time more market-oriented and without all the accompanying rationalization that had been in the air after 1918. The "energy imperative" was a mere maxim for times of need; the idea that not increasing energy consumption, but rather the economical use of energy could be a sign of progress was still out of the question for most people. Even such a critical mind as Kurt Pritzkoleit was shocked by the fact that in 1950 in the Federal Republic of Germany, per inhabitant three percent less primary energy was consumed than in the GDR.[102] The situation after the Second World War gave many an opportunity to think about the

the first post-war period, especially as some of the guiding principles of the heating industry were still the same. A review from 1949 notes that

The "buzzword of power plant engineers" after the First World War was initially "coupling of power and heat generation", then "high-pressure steam" and finally "use of low-value fuels". When cogeneration crossed company boundaries, it collided with the regional monopoly efforts of the energy supply companies, and the transition to higher pressures came up against safety limits. In the first period after 1918, when attention was focused more on people than on large-scale technical projects, there was much talk of improving the training of stokers; in contrast, in the innovations discussed in 1924 for "large-scale firing", "the art of the stoker was replaced by that of the engineer". The firing engineers preferred to seek technical progress in the transition to larger units without fully appreciating the problems of *upscaling: For* too long, furnaces had been a "black box" for the scientific community, populated by sinister characters. "Cheap little combustion chambers" were considered an "American way" that was held in low esteem. During the Nazi era, however, the capacity of individual turbine units was limited to a maximum of 85 MW in view of the air war, while American power plants already exceeded 200 MW.[103]

Until then, pulverized coal was an inferior fuel that was not allowed to be burned in the urban furnaces of the time for environmental reasons. However, when coal firing had to compete with gas and oil firing, it was pulverized coal that promised a similarly perfect firing technology: with mechanical feeding, any level of controllability

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and almost complete combustion. According to an assessment from 1924, the industry had "probably not devoted as much intellectual dedication and material sacrifice to any combustion technology issue [...] as to the issue of pulverized coal firing". The "astonishing triumph of pulverized coal firing by the American power plants" in the first half of the 1920s fascinated many German engineers; however, it came at the price of higher capital and operating costs and, initially, increased environmental pollution. The surprisingly enormous fly ash emissions from a pulverized coal-fired power plant commissioned near Herne in 1929 became a "key experience" for the entire energy industry. It also turned out that pulverized coal firing required larger combustion chambers and improved cooling equipment. Whether this firing technology, even if it was optimal in terms of thermal efficiency, actually improved the overall economy became doubtful, and there was a swing back to grate firing.[104]

From the very beginning, coal liquefaction and coal gasification were even more fascinating than pulverized coal firing; gas had previously only been a by-product of coal combustion and coking. In 1913, Lenin described the direct extraction of gas from coal seams as a "gigantic technical revolution" and considered it a fact. However, coal gasification has remained at the experimental stage to this day; at times, the high-temperature reactor was justified by the possible combination with coal gasification, without this prospect getting much further than the paper project stage. Not only economic, but also serious ecological considerations stood in the way.[105] Coal hydrogenation became IG Farben's riskiest large-scale project, which was only saved from open collapse by the National Socialist policy of self-sufficiency. These projects no longer had anything to do with prudent "heat management"; rather, they served to make coal combustion technically more elegant and to expand the range of applications for coal.

In principle, *combined heat and power generation* is an obvious choice wherever electricity is not generated by hydropower but by converting thermal energy and where there is a demand for heat in the vicinity of the power plant. It was therefore particularly suitable for municipal power stations close to consumers and in heavy industry, which required large quantities of drive and heat energy. The advantages of combined heat and power generation were easy to understand as soon as one thought in terms of the heat economy and the "energy imperative". In 1900, the first European electricity plant that also supplied district heating went into operation in Dresden. Combined heat and power generation became a German specialty for a time. In the 1920s, industry's own power generation - and thus the opportunity for industrial use of waste heat - was still in its infancy.

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This was not only due to an autonomous approach to energy, but also for reasons of operational safety, as the overland lines were still quite susceptible to thunderstorms and damage to insulators at the time. The conditions for decentralized combined heat and power generation were ideal, especially in a conurbation such as the Ruhr district, where industrial waste heat was produced in abundance, and the counterforces against the large electricity producers' efforts to gain a territorial monopoly were correspondingly strong at first. Elsewhere, it was complained that "the monopoly of the power plants often proved to be a Chinese wall" when it came to waste heat utilization.

Efforts to develop combined heat and power reached their peak during the coal shortage after 1918, but waned in the 1920s. When the acute need was over, the different ways of thinking of machine builders and heating engineers had an inhibiting effect. Optimizing the efficiency of the machines led in a different direction than striving to utilize waste heat. Even more so, the electric drive was a distraction from heat efficiency aspects. A thermal engineer complained in 1924: "It is almost tragic when you consider how anxiously the efficiency of boilers and machines is guaranteed and tested as long as the energy is still called 'heat', and how carelessly energy is managed as soon as it only flows as invisible and impalpable 'power'."

Ostwald had pointed out in 1907 that the "reality of energy" "appears most clearly [...] in electrical energy". The abstraction of "energy" found its technical correlate in invisible, ubiquitous electricity; the term "energy" became a synonym for this in official usage in the 1930s. But the tendency of the electric party was towards expansion, not towards the most economical use of primary energy sources. The equation of energy and electricity undermined the "energy imperative". Around 1924, there was a temporary confrontation between the electricians and the heat economists in engineering circles; they called each other "calorie catchers" and "calorie thieves". However, the pioneers of electricity were at the heart of the rationalization movement; their assertiveness far exceeded that of the heat economists.[106]

In the heavy industry of the 1920s and 1930s, the "German way" emphasized the "pooling of operations" in the sense of the "heat economy". "Heat economy" meant the use of blast furnace and coke oven gases and "the technology of the economically optimal flow of energy between the previously separate energy budgets of the blast furnace and the steelworks". The use of blast furnace gas first began in heavy industry in Lorraine, where it was already associated with a trend towards vertical concentration in iron processing, which provoked the Ruhr. Since about

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In 1908, Stinnes and Thyssen pushed ahead with the use of blast furnace gas on the Ruhr on a large scale; the heat economy was an integral part of a vigorous expansion policy. Gas was now also used as a fuel; for this purpose, the gas engine designed for small-scale operation had to be further developed into a large-scale engine. As early as 1911, an article on the "Triumphzug der technischen Wissenschaften" ("Triumph of technical sciences") to represent *Germany as a world power*, the large gas engines were a "specialty excellently developed in Germany", where the Reich was "far ahead of all other countries". In terms of gas engine size, German industry even ventured far beyond the usual dimensions in the USA. The combination of heavy and electrical industry created by the gas engine was the basic technical idea of the Stinnes Group; however, this fell apart in the post-inflationary phase of rationalization. The "economy of blast furnace gases" (Sohn-Rethel) was only partially in line with the economic efficiency of the company as a whole; with monomaniacal consistency, it became a prime example of the irrational excesses of "rationalization".[107]

Vertical concentration - the "path upwards to the primary product, downwards to the finished product" - was a sign of particular "strength" in the eyes of Walther Rathenau in 1918. While the focus was initially on combining blast furnaces and steelworks, collieries and coking plants, it was a sensational step when Gutehoffnungshütte moved into mechanical engineering and across the Main line in 1921, acquiring the majority of MAN. Overall, vertical concentration did not really follow a technical logic; in some cases, it was at odds with technical specialization. For many individual components, specialist companies were able to make much better use of mass production methods than large companies, which wanted to produce everything in-house wherever possible; therefore, from a technical point of view, mass production not only favored the large companies, but also the supplier industry.

Even the direct combination of steelworks and rolling mill, seemingly so obvious in its heat-economic advantage, brought only limited benefits; because the production made possible by the combination in one heat was, as the Enquete Committee stated in 1930, "only carried out with relatively little material, to which no special demands are made". This was not only a question of technology, but even more a question of organization. Even at the height of "rationalization", there was no talk of even halfway complete utilization of blast furnace gases; as late as 1928, the Ruhr Settlement Association complained that "day after day, the surplus gas that can no longer be used there is burnt in huge flares in the large smelting works without any use or purpose".

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The "path upwards to the primary product" and the optimal use of German resources should have led, if followed consistently, to efforts to utilize the poor ore deposits that were widespread in Germany; above all, the National Socialist autarky politicians wanted to see this as the "German way" of heavy industry. However, the industry gave the impression that this task was technically unsolvable; the German-American metallurgical engineer Hermann Brassert had to be called in to build the "Reichswerke Hermann Göring".[108]

As was the rule with industrial concentration in the 1920s, the founding of IG Farben was also justified as "rationalization", in particular as a requirement of increasingly complex industrial research - the Fordist model of mass production was not suitable for German chemistry. However, research remained decentralized even after the merger; there is no technical logic to the creation of what was then the largest German group. There was, however, the reverse connection: the new corporate dimension influenced the technological strategy by giving the coal hydrogenation project broader support, i.e. by promoting an economically irrational project monomania.

Hardly anywhere else was the doctrine of improving economic efficiency through growth in size and the connection between large-scale economy and large-scale technology so eloquently and aggressively championed as in the production of *electricity*, which became a public concern in the 20th century. With Emil Rathenau, the project of electrical centralization was "with multi-thousand-horsepower machines that automatically and silently supply millions of cities with light and power" was initially a vision that was ahead of the state of the art. At that time, German engineers were still wary of large machines, the risks of which were not yet fully appreciated. And yet the idea of a large-scale networked supply system was already one of the "youthful dreams of electrical engineering" long before the necessary technical basis existed. When the first power plants were built, a specific cost advantage of larger plants was calculated for Germany even in comparison to America; and while in the USA, where progress in power plant technology was more cautious, the power plants were initially expanded by adding small and fast-running machines, Emil Rathenau relied on the large, slow-running dynamo machine: a technically daring leap that initially met with skepticism at Siemens.[109]

The trend towards growth in the size of power plants was given a new boost by the needs of the war economy. RWE's Goldenberg power plant, which was gigantic by the standards of the time and initially did not appear to be profitable, was salvaged by aluminum production. While in the USA

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the "Giant Power" plans that flourished during the war suffered a setback during the peace, this trend continued in Germany after the end of the war. This growth in block sizes was a German exception at the time, as was the plan for a nationwide interconnected grid, which was at least partially realized: Not even Parisian centralism was able to inspire a similar project in France at the time. Electrification in Italy took place within an even narrower regional framework. In Germany, the growth in size was justified by the advantages of uninterrupted, even utilization of the power plants: There were always "electricity valleys" to be filled by developing new sales areas. The different attitude in France and Italy can be partly explained by the fact that hydropower was considered a national energy source there. Water can be dammed up when the momentary energy demand falls; coal-fired power plants, on the other hand, have to heat up steam boilers to increase output: In this respect, from a purely technical point of view, the need for even capacity utilization is much stronger there. In the case of hydropower plants, however, a similar interest may arise from the high capital costs.

But the pursuit of uniform capacity utilization did not necessarily lead to *economies of scale*. In the early days, the safest profit was achieved with a small network of direct current consumers with relatively even demand. As Hjalmar Schacht, the later author of the Energy Industry Act of 1935, emphasized in 1908, the state had to intervene to ensure that the electricity industry made progress in terms of concentration. At that time, a favorable balance of the daily load curves was most likely to be guaranteed in a manageable communal framework with secure electricity consumers. When electrification penetrated the countryside, the situation initially became unclear and unstable; it could only be consolidated by further boosting electricity consumption and by taking over municipalities. This resulted in the propagandistic attitude of the electrical industry and the demand for a territorial monopoly for electricity suppliers. This was justified with the economic stimulation effect of the electrification of rural regions and the cost degression with increasing block sizes. However, it was uncertain up to what size this degression would continue.[110]

For the private sector, the ideas of large-scale power and large-scale interconnection were initially a double-edged weapon, as they gave the nationalization plans of the war and post-war period a technical rationality. It was no coincidence that a nationwide network system was first developed in Bavaria, where Oskar von Miller, favored by the mood of the times, reactivated state-run traditions from 1914 onwards. This involved the Walchensee plant project, which became the largest hydroelectric power plant in Europe after the war; the large hydroelectric power plant

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the responsibility of the state could not be seriously disputed. It was different with coal-fired power plants. When AEG director Georg Klingenberg - at the time the leading expert on large-scale power plants, whom Walther Rathenau had brought into the war raw materials department - put forward the plan for a state-Prussian interconnected system in 1916, he met with resistance not only from RWE but also from the municipal electricity companies. When RWE, which granted the participating municipal associations a majority shareholding in 1920 and in this way expanded its alliance with municipal interests, pushed ahead with its north-south line from 1924, which was to connect the coal of the north with the hydropower of the south, this was a strategic counter-move against the state interconnection plans. A real battle developed between RWE and Prussia over Frankfurt: this was settled in the "Electric Peace" of 1927 by a territorial demarcation.[111]

The capacity growth of the power plants was accompanied by new technical dimensions, not only in the development of hydropower: lignite mining, which was the basis of the Vorgebirgszentrale (later Goldenberg plant) and the Golpa-Zschornewitz power plant and was being driven forward more strongly in Germany than anywhere else in the world at the time, quickly reached an industrial level in its methods and formed a sharp technical contrast to hard coal mining, where underground mechanization progressed only slowly. As early as 1907, the "iron miner", the first usable cutter excavator, was used in opencast lignite mining. If Paul Silverberg, the leading man in Rhenish lignite, emerged at times during the Weimar Republic as the political antipode to the Ruhr magnates and declared himself in favour of an arrangement with the Social Democrats, this openness had its technical basis in the high degree of mechanization of lignite mining, which made it much less sensitive to wage increases than was the case with hard coal. In 1929, for the first time, more electrical energy was produced from lignite than from hard coal.[112]

The interconnection between large power plants required lines with "maximum voltage": at the Frankfurt Electrical Exhibition of 1891, the 15,000 volts excited the technicians, 110,000 volts were reached in 1918. Above all, however, the construction of large power plants required a considerable increase in the capacity of the drive machines in order to utilize the technical possibilities of concentration. After the turn of the century, the construction of power stations led to the breakthrough of the steam turbine over the reciprocating steam engine, which had to be much larger for the same output. The steam turbine, a "truly revolutionary invention" (Mayr), improved the use of steam power with the principles of rotation and acceleration; it required a more theoretically trained type of technician. The steam boiler, seemingly

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a conventional and safe technology, had remained; but the steam turbines placed new demands on the steam boiler design.

In March 1920, a boiler built in 1917 exploded at the Reisholz power plant near Düsseldorf; the catastrophe, in which 28 people died, caused great consternation at a time when the danger of boiler explosions was thought to have been averted. The subsequent inspection of all large boilers yielded such "devastating results" that a "boiler epidemic" was diagnosed. At that time, the "Technical Association of Large Boiler Owners" (VGB) was founded, which was also intended to enforce higher quality standards on the iron and boiler construction industry by clarifying the risks of accidents. The increase in boiler performance and loads continued: While the boiler that exploded in Reisholz had still had an operating pressure of ten atmospheres, by 1928 the company had already ventured up to 100 atmospheres. Fritz Marguerre, the builder of the large power plant in Mannheim and one of the pioneers of steam turbine technology, admitted a human age later that, in retrospect, "one could almost speak of a cluelessness tempered by safety coefficients" in the large-scale engineering of the time. Whereas Riedler had once mocked all those who believed they could rely on "experience" in large-scale machine construction, the 76-year-old Marguerre confessed that the power plant engineers had only made progress through "intuition based on experience".[113]

The technical opportunities offered by electricity encouraged an early rush to scale. Emil Rathenau asserted in 1914 that the "technical possibilities of electricity production on a large scale" were "almost unlimited":
"It would be quite possible for Europe's entire demand for electrical energy to be produced in one place", and the centrally produced electricity could even be routed beyond Europe. The high transmission costs were apparently only a temporary problem; combined heat and power generation and the reserve capacities required in the event of the failure of such power plant giants were not an issue. For the 1930 World Power Conference, which met in Berlin, engineer Oskar Oliven, a member of the Loewe AG board, drew up a plan for a European high-voltage grid that would combine the hydropower from Scandinavia to the Balkans, from Spain to the mouth of the Volga and also be supported by the coal deposits located in this huge area. In 1925, Riedler calculated that for the same price of one pfennig, at which the energy of one kilowatt hour could be transported 165 kilometers, the same amount of coal could be transported 500 kilometers! Even transporting electricity from the Ruhr to the North Sea was no longer worthwhile; it was cheaper to transport the coal instead.[114]

Such facts were the weighty argument for Riedler's student and power plant engineer Franz Lawaczek, who was an NSDAP expert on technology

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and declared war on the centralization and interconnection strategy of the energy industry. Other sources at the time also calculated that the daily load curves of the German power plants were so similar that a large-scale interconnection promised only a slight improvement in capacity utilization. A particularly serious argument from the National Socialist point of view was the vulnerability of a centralized energy supply in the event of war. Therefore, a more decentralized energy policy was initially to be expected in 1933. However, plans of this kind were linked to the petty-bourgeois social reformist wing of the NSDAP, which was quickly overplayed after the seizure of power. The Energy Industry Act of 1935 even gave the regional monopolies of the energy centers the legal basis that had been lacking until then. The German Reich made a name for itself internationally as a model country for centralized power supply. Several industrial rearmament projects and the Four-Year Plan - aluminium production and high-pressure synthesis in the chemical industry - also helped to make the position of the large power plants unassailable.[115]

Even after the Second World War, the large-scale power and interconnected power industry emerged stronger as, for some unknown reason, it was less affected by the air raids than the industrial power supply. The battle between lignite and hard coal for the energy market, which broke out again for a time after 1945 on the Rhine and Ruhr, was also settled, and both sets of interests worked together against reluctant municipal energy suppliers in the further expansion of the North-South network. As before and after 1918, the Second World War and the first post-war period also saw a "Turn to hydropower" and a coal-hydropower combination became attractive due to the coal shortage. In 1948, in defense of the interconnected economy, RWE even attributed "paramount importance" to hydropower and proclaimed a philosophy of regenerative, "eternal energy sources". The new debate about the Verbund economy continued into the early days of nuclear energy development. The reference to the "unacceptability of transportation" of lignite was one of the main arguments in favour of large long-distance pipelines; in the case of uranium, on the other hand, transportation costs were irrelevant: So you can understand why some municipal power stations initially saw their chance in nuclear. In turn, RWE consolidated its north-south line with the first experimental and the first demonstration nuclear power plant (Kahl and Gundremmingen). However, RWE's technical director Heinrich Schöller justified the decision in favor of Kahl with the classic argument "that if the state wants to make mistakes by hastily building (nuclear) power plants, then we'd better make these mistakes ourselves in order to keep them under control".[116]

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Was there an alternative to this course of events? The centralist party had the consistent and assertive alliance of interests and the big, impressive concept on its side. Until the thirties, the opposing party to the centralist alliance was not insignificant; it ranged from the Prussian treasury and municipal associations to small and medium-sized electrical engineering companies. Even as Federal Chancellor, Adenauer, the former Lord Mayor of Cologne, sought to support the energy autonomy of the municipalities. But this front had an overall partisan and defensive character: at least that is how it appeared in the era of "rationalization". Not even the weapon of combined heat and power generation was used consistently.

Lawaczek, however, had a big idea: his concept of a decentralized energy economy was combined with the vision of a future hydrogen era and a technology emancipated from the profit motive. But the hydrogen economy was a phantom, and he quickly found himself politically sidelined, even if Hitler sympathized with his views internally. Fritz Marguerre, who fought against the omnipotence of the large-scale association after the Second World War, was a power plant engineer of stature and with communal backing. However, he embodied the urge to increase capacity in a striking way. From his point of view, too, the only alternatives for an energy supply company were growth or "infirmity and a long death". He was the first to venture a boiler pressure of 100 atmospheres; around 1960, the over 80-year-old was still advocating the construction of reactors with steam superheating, an avant-garde concept of the time.[117] A historical alternative to *economies of scale* existed only in individual elements, but not in an assertive coalition of actors.

6. German ways of motorization

The car demonstrates more blatantly than almost any other technical utensil the need to go far beyond mere mechanisms in a history of 20th century technology. A history of the car worthy of the name would not only be a history of engines, but also of marketing and design, of the co-evolution between technical equipment and customer wishes, and even more: not only of car production, but also of the motorization process and its immense consequences. There is no doubt at all about the historical significance of this process: not only the cities and roads, the industrial structures and foreign trade interdependencies, but also the everyday and vacation behavior of the

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most people, the relationship to technology and the environment, in sum the entire "second nature" of man was changed by the car. The car was "the first highly technical machine ever to be available to its owner for self-determined use"; it also enabled non-technical people to have an intimate relationship with mechanical technology.[118] Nevertheless - or precisely *because of* this wealth of aspects? - the flood of motorization in the
So far, the 20th century has not really been able to recognize a historical figure. Unlike the triumphant advance of the railroad in the 19th century, it seems like a natural process without a history, in which there are no actors, decisions or epochs. The difficulty in coming to terms with this topic historically corresponds with society's helplessness in the face of automobile traffic.

For this very reason, historical access could help to make people aware of the course of motorization as a social decision-making field.

The motorization process as such does not seem to require any special historical explanation; it is now taking place more or less in almost every country in the world. However, there are significant national differences in the details of this process. In an international comparison, it is difficult to ignore a certain special role played by Germany and a historical change in Germany's relationship to motorized transport is particularly striking. In the first half of the 20th century, German motorization progressed relatively slowly, considering that the car was first invented in Germany. It was not until the 1950s that a historically unique national identification with the car developed in the Federal Republic. Until the 1920s and 1930s, France and the USA were the car countries from a German perspective; in the meantime, the Federal Republic itself has become a bad car country from an American perspective. For a long time, there was popular outrage in Germany against speeding; in the end, however, the Federal Republic became the most persistent opponent of a speed limit. A role reversal that is reminiscent of the psychological model of "identification with the aggressor"!

However, it would not have been possible without a variety of state-imposed framework conditions: from road construction, traffic regulations, criminal prosecution practices, liability, car taxes and tax allowances to rail and tramway policy. As early as the 1920s, it became clear that the extent of bicycle traffic could also be strongly controlled by municipal cycle path construction: Magdeburg thus became the "City of Cyclists in Germany". Berlin city planners, on the other hand, pushed the bicycle to the margins in their American visions before it was actually pushed to the side of the road by cars: Old photos document that in the 1920s

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years ago, even pedestrians and cyclists were still crossing Potsdamer Platz.[119]

The First World War brought an initial breakthrough for the car, although its inflationary consequences plunged part of the middle class into poverty. While "national" motives had tended to benefit the railroads before 1914, motorization after 1918 seemed necessary and unstoppable, not least from the perspective of national power politics. The superiority of the USA also seemed to demonstrate the indispensability of the car for "boosting" the economy. In 1928, Friedrich Pflug, Ministerial Councillor in the Reich Ministry of Transport, asserted that since the war, nobody doubted "that the motor vehicle is indispensable for the intensification of our economy". The war directly benefited lorries in particular, whose development had already been subsidized by the military years before 1914. However, as truck traffic put the greatest strain on the roads that had not been equipped for it, a sharp conflict immediately arose here with municipal and homeowners' interests; in addition, there was the opposition of the Reichsbahn. The development of passenger car technology was influenced by the fact that many aircraft manufacturers sought a livelihood in the automotive industry after the end of the war: This reinforced the trend towards small, fast-running and correspondingly loud engines, which was in any case encouraged by taxation based on engine capacity and proved to be a disadvantage compared to the American competition in the mid-twenties.[120]

After 1918, owning a car became a status symbol for those who still had money. Even in a small town like Herford, it is reported that "since July 1920, passenger cars have been springing up like mushrooms in the wealthy circles of big business, trade and industry. Members of the liberal professions, such as lawyers and doctors, have also started to buy cars." Was mass motorization only a matter of time even then? The contemporary testimonies convey a contradictory picture in this respect. From 1921 to 1929, the number of cars in Germany grew from around 60,000 to 422,000; this sevenfold increase in eight years was, in terms of the steep rise in growth, an "almost American development". General Motors bought the Opel company in 1929 on the assumption that the era of mass motorization was imminent in Germany. However, in the expansion policy of its founding years (from 1926), Vereinigte Stahlwerke does *not* seem to have speculated on the coming mass motorization. Not even one percent of the growing German population owned a car! And the economic crisis soon put a kink in the growth curve. The hope that motorization would act as an engine of economic growth was bitterly disappointed.[121]

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Nevertheless, Fritz Kummer, editor-in-chief of the Metallar- beiter-Zeitung, announced in 1930 that the "revolutionary automobile" would "serve the cause of the revolutionary working class": this "funny purring and devilishly whirring factory on wheels" had "thoroughly changed our entire public and social life" and brought about a transformation in technology and production methods that would now also be transferred to wage policy. This
However, the "Fordist" argumentation primarily reflected the interests of the workers employed in the automotive industry. The engineer and automobile journalist Louis Betz, a controversial champion of the "people's car", believed he could state in 1928 that "today" people wanted to "move away from the railroads and towards automobile traffic", but three years later he remarked that there were "some groups" who were trying to prevent further automobilization and could also cite reasons for this. Ford had just been the winning argument for mass motorization; now, however, Betz railed that the reference to the USA was the "most foolish thing that could be put forward in favour of motorization", as the USA was a country with few railroads. An article in the *Weltbühne* (1926) mocked the "impression alcoholics" who, when they returned to Berlin from Broadway, were depressed by the "carless asphalt patches of Potsdamer Platz". The author calculated that there would be "a car every eleven metres" on German roads if every fifth inhabitant had a car here, as in the USA, while the road network remained the same; anyone who wanted to transfer American motorization to Germany would therefore be suffering from "carism". It was not only the Americanization fad, but also the mockery of it that characterized that time. In 1931, Ferdinand Fried already believed that motorization was coming to an end; the combine harvester was merely a "gleaning of the motor age".[122]

And yet the journalism of the 1920s is teeming with references to the fascination exuded by the car. If not public opinion, then published opinion could give the impression that even then everything was pushing towards mass motorization. The archives and regional newspapers, however, sometimes convey a very different picture: there is still a flood of complaints about the growing number of cars on the road and about the recklessness of an automobilism that is still rooted in the tradition of hunting. Not only the love of the car, but also the hatred of the car has its history. Even if the public was already noticeably more hardened against car accidents than before 1914, when even the injury of three horses by a car excited the local Munich press for days, even a partisan of the automobile still registered a "general hostility towards cars" in 1925. Hermann Hesse's *Steppenwolf* (1927) indulges in the fantasy of how pedestrians, long hunted by cars, in turn hunt down the "fat, beautifully dressed" cars.

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dressed, fragrant" motorists to "beat them to death along with their big, coughing, evil growling, devilishly purring cars".

The majority of the population still had no reason whatsoever to feel like car owners, and obviously did not, but saw the conquest of the road by the car as an illegitimate act of usurpation. Those contemporaries who still had vivid memories of the pre-car era experienced how the car transformed the street - until then also a place of communication and a preferred residential area - from the ground up. The politically relevant core of the resistance to growing car traffic lay with the smaller municipalities, which repeatedly insisted on retaining the old speed limit of 15 kilometers per hour within towns and villages, which was based on horse-drawn vehicles.[123] However, this resistance at the time, like the municipal opposition to the centralization of electricity production, had an air of petty partisanship; it lacked an effective alternative concept that could have attracted a consensus of forces.

The call for the "people's car" was already heard in the early years after 1900 and became a leitmotif of car journalism in the 1920s under the influence of Henry Ford. But to many car enthusiasts, the cheap cars that kept coming onto the market seemed like freaks and caricatures. The most successful car of the Weimar Republic, the Opel
"Laubfrosch", was a replica Citroën; but even this car, which was already produced on an assembly line and at times set a production record of 100 units per day, did not become a real "people's car". When German car manufacturers tried to bring out a "people's car", they could not escape the dilemma that a car was generally not bought purely for reasons of utility, but also out of fascination: And a small car could not offer this, while it was still far too expensive for a sober-minded normal earner. This insight was deeply rooted in the majority of the German car industry. Looking back, it is astonishing how stubbornly the industry resisted the Nazi dictator's Volkswagen plan even after 1933, despite the fistful of flattery and grandiose promises made to it by the new regime. The Nazi regime had to take Volkswagen production into its own hands. The industry's resistance was based on a realistic assessment of the market: despite massive Nazi propaganda, the number of people who saved up for the "KdF-Wagen" remained far below the number that would have made the production of the "people's car" profitable.[124]

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Figure 34: "Yes, the body is made entirely of steel!" From a KdF brochure
"Shortly afterwards, the war began and the KdF car remained a dream of the future for German savers. In contrast to American motorists, it was considered characteristic of German motorists that they not only wanted to use their cars, but also to handle their technology with connoisseurship. "Made entirely of steel": Until then, the bodywork of many automobiles had still contained wooden elements. Twenty years later, the designers of the "Trabant" were proud to manage *without a* steel body!

For a long time, the people's car of the future remained a mere fiction: the fiction of a car lobby that was still on the defensive and had to prove that the car was of public benefit. The hustle and bustle of a vociferous cartel of interests, which - supported by associations and magazines - propagated the unity of all motorists against the opponents of this new technology in an often irritable tone, had been a constant since the first parliamentary elections.

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The car's success was also characterized by the tartaric battles over speed limits and liability (1905-07). Here, too, a new technology generated a pronounced group coherence, at least as much among the users as among the producers. Until the 1950s, the triumphant advance of the automobile was an example of the "Olson paradox": that a compact minority interest is more assertive than a diffuse common interest. As late as 1954, Adenauer joked in a conversation with Fritz Berg, chairman of the Federation of German Industries (BDI): "If I were not chairman of the strongest party in the Federal Republic, I would found a party against the automobile that would be even stronger. "[125]

While the "people's car" was not even seriously pursued as a goal by the automotive industry in the interwar period, another German path to motorization emerged in the course of the 1920s: the cheaper *motorcycle*. Until then, England had been the leader in motorcycling, as it was in cycling - while in the USA the motorcycle was already being pushed back by the car - but after 1925 Germany moved to the top. From 1926, the number of motorcycles in Germany exceeded the number of cars, and this lead lasted until 1957, marking an era of motorization. More than in car production, there was a German version of "Fordism" in motorcycle construction: the DKW factory in Zschopau, which introduced assembly line production in 1925 and had been the largest motorcycle factory in the world since 1928, launched a "people's bike" for 420 Reichsmarks in 1931. Nevertheless, motorcycle construction - at least as much as car construction - remained a field of tumult for passionate hobbyists who were far removed from business calculations, and the variety of types was correspondingly large. It was far from certain that the car was the ultimate goal of motorization. Until the second half of the 1950s, industry circles still saw a promising gap in the market between motorcycles and cars. It was not until around 1958/59 that the product strategy of scooters and mini-cars reached its definitive col- lapse.[126]

In the 1920s, the German automotive industry had not yet entered the age of mass automobilism. Its production lines were partly determined by specifically German technical traditions, such as the preference for heavy cars: Germany was then more a country of steel than of aluminum; its specialty was heavy engineering. This may have contributed to the fact that German small car production did not even meet the needs of the domestic market. Daimler-Benz's production strategy was partly influenced by the diesel engine and also by its experience in the construction of aircraft and military vehicles - a legacy of the First World War.

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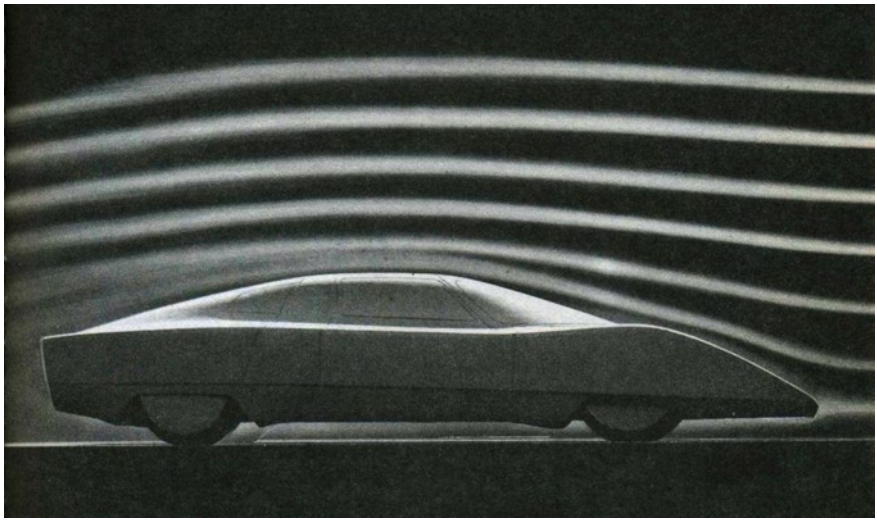

Figure 35: Clay model of a streamlined car in the wind tunnel, where it is determined which design minimizes air resistance. Aerodynamics first gained practical importance in aircraft construction. It was only much later that it began to exert a significant influence on the car body: when higher top speeds made air resistance increasingly noticeable and the aesthetic preferences of motorists moved away from the old model of the coach.

The company reacted to the global economic crisis by deciding to focus more on truck and bus production.
Partly influenced by aircraft construction, the streamlined shape began to gain acceptance in Germany in 1932, even if it initially irritated the public, who still remembered the aesthetics of the carriage.
"Aerodynamically almost perfect shapes were already known in the 1920s, but were not relevant in times of moderate speeds and fuel prices - rather, the resulting design was a psychological obstacle to sales." (Lutz Engelskirchen) The impetus for this revolution in design came from technology, not marketing. This priority was typical for the German car industry - according to an American judgment - even as late as 1980. However, technology as such provided little impetus for standardization and typification in the car. Although certain basic structures remained tenacious, this complex product, which had to be adapted to very different situations and served buyers to a large extent as a means of social distinction, offered a multitude of optimization possibilities, unlike steam engines or turbines. To this day, the question of which is the best car is an almost inexhaustible source of discussion. Even the discussions taking place under pressure from above

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Figure 36: Advertisement for the Hanomag small car in the *Berliner Illustrirte* (1926). Mockers rhymed: "Two pounds of sheet metal and a pound of paint / The Hanomag is finished!" The advertisement praised the little car as "unprecedentedly cheap to buy and run"; however, it was not able to achieve anywhere near the popularity of the later VW Beetle. For car fans, it was not a real car. The carriage-like body was still untouched by any aerodynamics. After all, this car was not meant to be a racing car!

in the committee set up in 1938 to rationalize the automobile industry did not lead to any results on their own.[127]

It was not only the companies' and engineers' striving for originality, but also the German market conditions that favored the diversity of car production types. Even Deutsche Bank, which would have preferred to force a major merger of the car companies around 1926, attached importance to maintaining the broad product range. In Germany at the time, there was no mass motorization on a broad front, but rather several specific motorization processes linked to certain groups and types of buyers. Even though the car was no longer purely a sports and luxury item in Germany, as a study from 1929 notes, "the purchase of a car

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was considered much more important than on the other side of the Atlantic"; the car should therefore also be much more stable. The American - as one car enthusiast wrote in 1938 - wanted the engine to be as quiet as possible, whereas the German wanted to feel the "living power" of the engine and also "know how it runs, how it works: The German also looks under the hood when he doesn't have a breakdown, the American never does." It was precisely at this time, however, that the Austrian emigrant Ernest Dichter began to teach American car advertising that, contrary to popular opinion, cars were not bought as a means of transportation in the USA, but as a symbol.[128]

BMW boss Popp aptly remarked in 1931 that the "No. 1 Volkswagen" in Germany was the bus; this alone offered an economical way of mass transportation. During the Weimar Republic, public transportation in Germany experienced its greatest period of growth, whereas it had already reached its zenith in the USA in 1908. The Berliner Verkehrsgesellschaft (BVG), founded in 1928, boasted of being the largest municipal company in the world and the third largest German company after the Reichsbahn and IG Farben. The focus of Berlin's transport policy at the time was on the costly construction of the subway; the road was therefore already respected as the domain of the car. The architect Werner Hegemann did the same, and although he scolded the "wasteful subway railroad mania", he instead promoted elevated railroads. The Reich Road Ordinance of 1934 abolished the right of way of streetcars over other road users. The Nazi government ordered the closure of the tramway in Weimar, as it was inappropriate for the city of Goethe and Schiller.[129]

In his opening speech at the International Automobile and Motorcycle Exhibition in Berlin in 1936, Hitler blamed the ruling Social Democrats of the Weimar Republic for what he claimed was the "dismal decline of the motor and thus transport industry in general", as they "in accordance with the Marxist theory of primitiveness [...] regarded the automobile as something not necessary and thus as something superfluous and taxed it accordingly". In doing so, he assumed that the "longing" for the motor car, especially
"because it is withheld from our people, is particularly impressive in our country". The theory that the Weimar state deliberately inhibited motorization can be found even before 1933 and is still echoed in later historiography. From the point of view of the car lobby, car tax and third party liability, and even the obligation to obtain a driving license, were already indications of hostility towards cars. In 1931, Louis Betz, who wanted to abolish all of this, raged at the "apparatus of the authorities", whose alleged "fight" against the car was part of an "anti-industrial, Marxist way of governing" that was ruining the "terminally ill new Germany". His particular anger was directed at the railroad administration: "It's not about the fact that tens of thousands of people are working at

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The reason for this is that these tens of thousands are being forced into a different pace with the new automobile as a means of transportation."

As in the 1950s, the car lobby assumed that state transport policy was dominated by railroad interests. However, this was already less and less the case in the 1920s. Even in the Weimar period, the rail network was no longer being expanded, although rail freight transport was still on the rise until 1929. The Dawes Plan made the newly founded Reichsbahn the main bearer of the reparations burden: a situation that inhibited a generous innovation policy. The number of locomotives was reduced, electrification was only pushed forward to a limited extent; "rationalization" at the Reichsbahn meant above all austerity. In 1932, there was no train in Germany with a travel speed approaching 100 km/h. In the summer of 1933, the Reichsbahn put a diesel-powered high-speed railcar into operation between Berlin and Hamburg with a top speed of 150 km/h, which transported passengers from the Spree to the Alster in two hours and 18 minutes. In international comparison, however, Germany still lagged behind with high-speed trains for a long time, not least because of its adherence to the steam locomotive. Although the Reichsbahn obtained a compulsory concession for long-distance truck transport, it also sought to "draw on the truck, which was limited to local transport, as a federal comrade". The "organizational integration of truck transport into rail transport" was praised as a German peculiarity in 1926.[130]

In contrast to the pre-war period, investment in road construction in the 1920s far exceeded that for the railroads. But the task of converting existing roads for motor traffic was enormous and could drive heavily indebted municipalities to despair. In 1928, a district planning officer demonstrated in a study "that not a single one of our roads could withstand even average automobile traffic, because all the road substructures were more than inadequate". Until then, German road construction had lacked an engineering tradition. From the mid-twenties onwards, a turning point began to emerge; the reconstruction of roads for automobile traffic became the subject of targeted research. Tar and asphalt bridged the gap between road construction and chemistry. The technically optimal solution was not easy to determine, as it depended on regional conditions - such as winter frost resistance - and required long-term experience. As a result, there were initially many failures and conflicts between different concepts. Until 1933, however, almost all of the plans that were initiated had one thing in common: they were based on the

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car-friendly conversion of existing roads, not the construction of new roads.[131]

Plans for freeways had long been on the drawing board in 1933; the short Cologne-Bonn motorway route already existed; the question of freeways was already the subject of lively debate in the 1920s. Some automobile enthusiasts in particular were fierce opponents of freeway projects at the time, as their realization was inevitably at the expense of the reconstruction of existing roads with a limited transport budget. The Reich Association of the Automobile Industry took a stand against all highway plans around 1930. In the situation at the time, a planning focus on a transportation network specifically designed for the automobile would have strengthened the position of those municipalities that opposed the dominance of the automobile on inner-city roads. The "residential street with its stationary statics" was a logical correlate to the pure automobile road. Freeway or car-friendly expansion of existing roads: This alternative was linked to different concepts of the function of the car. The freeway - in concept and idea a counterpart to the railroad - meant that the car should be a means of long-distance transport competing with the railroad; the "nature of the motor vehicle as the most adaptable, most flexible, most mobile means of transport", on the other hand, was best served by a "widely ramified rural road network". At the level of motorization at that time, the construction of freeways was almost pointless; even today, the car functions predominantly as a means of transport for short and medium distances.[132]

What nevertheless prompted the Nazi government to build the autobahn? The answer to this question is more difficult than it seems from the perspective of a later time, when the purpose of the autobahn was self-evident. Such a massive preference for private transport over public transport - and Hitler not only made a formal declaration of love for the car, but also explicitly emphasized his aversion to the railroads - was in direct contradiction to the otherwise proclaimed basic principles of National Socialism. In the novels of the twenties, the car was favoured as an attribute of a sophisticated, "Americanized", egocentric lifestyle. It would therefore have made sense for the National Socialists to combat, if not the car per se, then at least unrestrained automobilism as a swampy flowering of metropolitan civilization, which was reviled as "Judaized", and rather to cultivate masculine, weatherproof cycling and motorcycling.

In 1931, none other than Fritz Todt, the later overlord of freeway construction, complained that an "invasion of the automobile on the country roads" had taken place without "impoverished Germany" being able to protect the roads "from the onslaught of automobilism" through appropriate expansion. The

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70-year-old Sombart, who called for the control of technical progress, endeavoured to anchor the fight against unrestrained motorization in national ideology. Moreover, mass motorization was at odds with the policy of self-sufficiency, at least as long as coal hydration did not provide cheap petrol or Romania and Baku were not part of the German sphere of influence. Military motives determined the construction of the autobahn less than was often assumed; the army command was not convinced of the military use of these roads, but rather feared their orientation value for enemy airplanes; surprisingly little attention was paid to military aspects when planning the route.[133]

Contrary to what the Nazi propaganda later claimed, Hitler's decision to build the autobahn was evidently not the result of a long-cherished and well-considered plan, but only came about in the situation of 1932/33. However, this decision was by its very nature not an isolated decision, but part of an entire strategic package, which included not only the "Volkswagen" plan, but also fuel synthesis, job creation through road construction and the war concept, which was strongly geared towards motorization; these different lines of action reinforced each other. But a psychological moment, an emotional calculation and an urge for monumental immortalization for posterity are also unmistakable in Hitler's statements on the subject of cars and freeways. At the Berlin Motor Show in 1933, Hitler declared that the motor car "belongs more in its entirety to the airplane than to the railroad", and he based this astonishing assertion on the history of technology: "The motor car and the airplane have a common root in the engine industry." Indeed, motorists could only enjoy the thrill of flying on freeways, preferably those which, as was the case under the direction of bridge builder Paul Bonatz, were preferably routed over valleys rather than along the valley floors. According to Hitler's wishes, the Germans should "get a feeling for wide open spaces": that was the only thing the Americans had so far ahead of them in the realm of emotions. There was no logical connection between the construction of the autobahn and the war, but there was a psychological one. "We don't want to evade! We are creating enough space to move forward, and we need a track that allows us to maintain a speed that suits us for long enough" - this is what the autobahns proclaimed in the words of construction manager Fritz Todt, who was appointed by Hitler as a was glorified as the "greatest road builder of all time" and whose stellar career reveals the opportunities of the technical expert in the "Third Reich".[134]

However, most Germans did not enjoy the autobahns until long after 1945. Now that type of collective pseudo-memory could develop.

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The mass motorization of the "economic miracle" era as a retrospective justification for the construction of the autobahn. The mass motorization of the "economic miracle" era as a retrospective justification for National Socialist freeway construction, indeed for the National Socialist war economy: a technicist meaning-making that rivals in its grotesqueness the rehabilitation of the atomic bomb through "peaceful" nuclear energy, of high-tech armaments through the "spin-off".

When the vehicle industry was looking for civilian markets for the heavy, all-terrain vehicles promoted by the war around 1918, agriculture was the obvious choice alongside road haulage. However, it seems premature for Günther Franz to suggest that "the age of tractors for agriculture" had already begun in 1917: until 1927, the number of horses in German agriculture was still growing and the subsequent decline was caused more by the crisis than by motorization. Up until the period after 1945, the tractor, at that time often jointly owned by several farmers, was mainly used on a subsidiary basis to cope with peak workloads. It was not until around 1954 that the tractive power units provided by tractors in Germany exceeded those of horses, cows and oxen.[135] Around 1918, the impetus for motorization came more from outside than from agriculture itself, which subsequently had to complain even more than before about debts, but less about a "shortage of people".

Henry Ford also posed a challenge to the motorization of agriculture: the lightweight "Fordson" tractor had conquered British agriculture during the First World War - a patriotic act at a time of war-related labour shortages - and also made inroads into Germany during the peace. In 1921, the Mannheim-based company Lanz launched the first
"Bulldog" onto the market, the ups and downs of which determined the future fate of this largest German agricultural machinery company. From 1926/27, it produced the Bulldog on the assembly line; compared to the Fordson, it advertised its higher tractive power and better fuel economy. In the 1920s, the "American challenge" was met more effectively with tractors, whose success depended particularly heavily on their adaptation to regional agricultural conditions, than with passenger cars. Tractor construction proved to be a technical field of its own, requiring specific experience and development processes.

While the trend in industrial technology was towards the integration of drive and tool, agriculture at the time needed an all-purpose drive, insofar as it could afford an engine at all. The tractor therefore displaced the motorized plough; it replaced the horse, not so much the human being, and in this respect fitted into conventional agriculture. While car designers were constantly experimenting with high-powered engines, Lanz's motto was: "The engine for the farm".

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Tractors cannot be single-cylinder enough"; until the 1950s, primitiveness and indestructibility of the technology and rigid adherence to the tried and tested were the trump cards here. While the development of fast-acting and easy-to-operate igniters was a key technology in passenger cars, the Bulldog's glow head, which had to be preheated with a blowtorch before the engine was ignited, apparently contributed to the popularity of this tractor and the emotional man-machine relationship. Nevertheless, the Bulldog did not become an agricultural counterpart to the Volkswagen. Even Porsche, the creator of the VW, had no luck in designing a "people's tractor" due to his lack of agricultural knowledge. More successful was the idea of cannibalizing wrecked cars to make agricultural vehicles; this tinkering could be turned into a real system at the Berlin car graveyards. The tractor only became ubiquitous on German farms in the 1950s. The more dependent farmers became on subsidy guidelines and advisors, the more the tractor became the last bastion of farming autonomy: hence the tendency of farmers to use tractors with unnecessarily high horsepower and, linked to this, to "over-mechanization", which is often criticized by agricultural experts.[136]

But this was still a long way off in the war and interwar period. Initial attempts to introduce the American combine harvester in Germany around 1930 failed. The combine harvester, whether powered by horses or an engine, was still a distinctly American technology that did not fit in with German agriculture. Not only was it more expensive than previous agricultural machinery, it also demanded "nerves of steel" from its operator in German weather conditions, as harvesting had to wait until the grain was "dead ripe". In this case, the machine not only had to be adapted to agriculture but, conversely, agriculture also had to be adapted to the machine, as the combine harvester was best used in agricultural monocultures. As Vormfelde, the scientific mentor of the later Harsewinkel "combine harvester king" Claas, made clear in 1931, the introduction of the combine harvester was actually linked to a "new world view". This "combine harvester era", in which the workforce in the construction industry shrank to the size of a small family, did not begin in the Federal Republic of Germany until the end of the 1950s, a time that also represented a significant socio-historical caesura in other areas of technology.[137]

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V. At the limits of mass production

1. Rupture lines in the history of technology in the Federal Republic of Germany: From the rule of consumption to high-tech euphoria

"No new discovery in any field is likely to have such a rapid and beneficial effect on industry as the application of what is already known," was a typical lesson in the history of technology during the reconstruction period. As long as we stare spellbound at the great technical innovations, the "economic miracle" era seems like an appendix to the previous era. In the early Federal Republic of Germany - in stark contrast to the GDR - technological progress was not a major topic and certainly not a political issue. Wilhelm Röpke, a leader of the new "ordo-liberalism" of national economics, had an anti-fatalistic attitude towards technology and declared the idea to be "completely inaccurate", "as if we had to passively accept whatever inventions were bestowed upon us by chance or natural logic". It was the time when Konrad Zuse's calculating machine stood unnoticed in a barn in the Allgäu region, when the inventor of an acoustically controlled lathe, Wolfgang Schmid, was nicknamed
"Lügenschmid" and when a Federal Chancellor governed who had invented an illuminated stuffed egg and whose most successful election slogan was "No experts!".

For a long time, post-war West German culture, whether in politics or technology, was a culture of understatement; in this respect, it differed very decisively from both the Nazi and GDR styles, and the new western state did not do badly with this. Even when the Federal Republic of Germany became the richest state in German history, the slogan "Who's going to pay for it?" from the time of the currency reform was still in the air; the first question asked about all projects was "what it costs and what it brings." When Eugen Sänger, the German space travel authority of the 1950s, recommended a flight into space in 1955 by saying that it was "just as expensive and just as adventurous as military aviation", many contemporaries could only tap their foreheads. As you can see, the ideas put forward by

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The founding years of West Germany, once so despised by many intellectuals, have their exemplary aspects.

The BDI chairman Fritz Berg, who came from a wire-drawing factory in Altena and produced bicycle spokes and mattress springs, was at least outwardly still something of the type of craftsman-entrepreneur who was given a new chance during the period of reconstruction. From the thesis of the

He was not interested in the "second industrial revolution" that was fashionable among intellectuals at the time. The astonishing successes of reconstruction showed that it was people and markets that mattered most, and that implementations were often more important than spectacular innovations. In the early fifties, rolling mills were the most technically prominent symbols of reconstruction; but the mass production of Negro kisses, which began in 1950 on special machines, was also a milestone for post-war Germany.

"eating wave" characteristic innovation. A comparison made in 1955 between the Dortmund-Hörder-Hüttenunion and an American steel company revealed that the "senior technical staff" in the American company was ten times as large as in the German company.

Nevertheless, the (not unfounded) confidence prevailed in German industrial circles at the time that it would be easy to catch up with the USA's technical lead, if it existed at all: after the currency reform, the VW plant already had "the largest and most modern automobile factory in the world" (Patrick Kresse). It was the most spectacular example of "Fordism" in the Federal Republic and yet - as Volker Wellhöner showed - it was precisely not a mere "copy of the American model", but a "creative synthesis of American influences and German traditions". The VW

The "Beetle" even surpassed the Ford Estate and became the world's best-selling car of all time, at times accounting for half of Germany's huge foreign exchange surplus.

Where German industrialists expected good business from American innovations, the "technology transfer" generally took place without too many problems - such as when BASF boss Bernhard Timm "nylonized" himself during his stay in New York in November 1949 in order to test the qualities of this synthetic fiber, which had been disparaged in the days of IG Farben, thereby gaining an unshakeable confidence in the future of nylon and henceforth directing BASF into this branch of production. With good reason, people did not stare spellbound at the *Manhattan Project,* the nuclear *Big Science*; rather, the experienced rationalization expert Kurt Pentzlin, who tried to introduce German entrepreneurs to American innovations, cited the invention of a walnut cracking machine commissioned by a chocolate company as a prime example of a useful regionalization idea from the other side of the

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The small gas explosion blew it open from the inside, thereby ensuring the integrity of the nutshell intended for decoration. For him, this proved the value of technical "ideas" - nothing to do with science-based "research and development"! While the 1950s were considered the golden age of science fiction in the USA, this literary genre left post-war Germans cold - at least until around 1958.[1]

Until then, even the chemical industry's investment policy had been more short-term than long-term. Karl Winnacker, however, who had been involved in alizarin and rubber synthesis at IG Farben before 1945 and was promoted to head of Farbwerke Hoechst in 1952, subsequently became the most prominent advocate of nuclear technology in the industry; the IG Farben tradition of self-sufficiency-oriented large-scale projects was on the horizon here. But even Strauß, as nuclear minister (1955/56), considered it advantageous to wait for the experience of other countries in reactor development, and expressed reservations about the construction of nuclear research centers even when these threatened to swallow up "millions" and drag on for "years" - people were not yet thinking in terms of billions and decades! The philosopher Ernst Bloch believed at the time that in "procrastination" towards civilian nuclear technology is an indication of the "late bourgeois throttling of technology". In the early days of rearmament, the German Industry and Trade Association doubted the benefits of establishing a German aviation industry, while the much smaller GDR threw itself into aviation at the time.[2]

In the late 1950s, on the other hand, a new era began in the history of technology. Since then, technical innovations have attracted increasing attention. While technology as such was hardly a public topic during the period of reconstruction, from then on there was an unprecedented level of publicity focusing on "high-performance" and "cutting-edge" technologies, on "new technologies" and "high tech"; the stimulus words changed over the decades. As with the rationalization movement of the interwar period, the technological euphoria was linked to the general climate of the time; as in those days, a distinction must be made between discourse and real history.

A whole range of observations indicate that a "saddle period" can be dated to the years around 1957: whether in terms of technological perspectives, economic history or everyday culture. While economic growth had been more extensive until then, from 1957 onwards technological progress was attributed a decisive role in maintaining growth. From this point onwards, the number of patent applications increased to such an extent that the Federal Patent Office temporarily found itself in a crisis. In 1957, unemployment fell below four percent for the first time; the shortage of labor became more of a technical problem than ever before in German history.

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Figure 37: Federal Economics Minister Ludwig Erhard plays a board game against an English Nimrod gaming computer at an industrial exhibition in Berlin in 1951 - and loses three times in a row, while Chancellor Adenauer, who didn't have a very high opinion of his Economics Minister anyway, is amused in the background. At a time when computers were still irrelevant in German industrial production, they caused an amused stir as a gimmick! Before the advent of industrial machines, slot machines had a centuries-old tradition that inspired fantasies about the future automation of industry.

nization impulse. A turning point can also be seen in the fact that the proportion of white-collar workers, which had stagnated from 1950 to 1956, rose "abruptly" from 1957.

Other, sometimes coincidental, coincidences reinforced the trend towards greater appreciation of technical innovations. In 1957, the Soviet earth satellite "Sputnik" was launched, and the "Sputnik shock" had a long-lasting effect in the Western world. Wernher von Braun, the former Nazi German rocket builder in Peenemünde and now the American leader in the rocket race, became a popular figure in the Federal Republic: there had never been such a career for a German technician in the USA. Like no one before him, he embodied the Old Shatterhand myth: the German who was sent to the USA as an American hero. In 1957, the first German nuclear program was drafted, albeit unofficially at first; in the same year, RWE independently began construction of the first German experimental nuclear power plant in Kahl am Main. Also in 1957, the nuclear conversion of the German Armed Forces was decided; a combination of military and future technology became apparent. In 1957, Siemens placed the first order for an electronic computer.

German crude oil imports, which had risen only slowly up to that point, rose steeply from 1957 onwards; the price of heating oil fell "virtually

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dramatic"; coal, which had experienced a boom as recently as 1956, fell into a permanent crisis quite abruptly and completely unexpectedly for contemporaries. Federal Economics Minister Erhard, who saw the energy monopoly of Ruhr coal as the
"Achilles heel" of the market economy, the Ruhr wanted to create competition by liberalizing mineral oil imports; this policy had an effect that surprised everyone and overtook the politicians in Bonn. At that time, mass motorization created a steep rise in demand for petrol; its production resulted in heavy fuel oil in the refineries, which from then on put coal under severe pressure.

This was the end of an era. For a century, coal had strongly determined the dynamics of Germany's economic and technical development; this period was now coming to an end. Even the chemical industry, until then one of the largest consumers of coal, whose greatest ambition before 1945 had been to produce synthetic oil from coal, now switched to petroleum, following the American model. Even Chemische Werke Hüls, whose site had been oriented towards Ruhr coal, switched to petrochemicals. This break with tradition did not take place without fierce disputes within the chemical industry. Even during the "oil crisis" of 1973, the
"Veterans of coal chemistry" at BASF took a breath of fresh air and rallied around Otto Ambros, who had built up the IG Farben plant in Auschwitz during the Second World War on the basis of forced labor and Upper Silesian hard coal. Such turnarounds in favor of coal chemistry were, of course, only
"Phantom pains of a technological age that has been a thing of the past since the mid-1960s" (Werner Abelshauser). In plastics production, now the strongest growth sector in the chemical industry, oil, which contained the required hydrocarbons ready-made, was much closer to the end product than coal. North Germany's industrial lead was gradually lost. From the 1960s onwards, Baden-Württemberg and Bavaria distinguished themselves as strongholds of the "new technologies", Bavaria - until then a relatively poor and industrially backward federal state - also as the preferred location for the new combination of chemicals and oil.

It was not until the 1950s that the age of the steam engine and the age of windmills and watermills came to a definitive end as a result of the tariff policy of the large electricity producers; in times of coal shortages and war destruction, people were glad to still have the old mills and had developed them further technically. In 1957, the traditional Solingen cutlery industry, once a symbol of German quality workmanship, began to decline. The decline was accelerated by home workers overreacting to the symptoms of the crisis and young people shying away from the industry.

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In 1957, the EEC and Euratom Treaties came into force. Mechanization pressure in agriculture became stronger than ever before; a stronger wind of international competition became generally noticeable. The following year saw the free convertibility of the Deutschmark. In 1960, American investments in the Federal Republic grew to over one billion dollars and subsequently increased by an average of 300 million dollars per year. The era of "unbundling" was finally over; even Erhard's fight against the cartels became, in the caricature of the time, quixotic; the dynamics of *economies of scale* were able to unfold anew.[3]

Until the late fifties, the two-wheeler and small car business was still flourishing; in the sixties and seventies, however, the car became a normal accessory of life. Even the airplane became a means of mass transport thanks to large aircraft: while the number of German air travellers was only 27,000 in 1961, it was two million in 1971 and 44 million in 1981.[4] While the atmosphere of the fifties was still largely characterized by austerity, puritanism and restorative tendencies, the sixties and seventies brought a deep break in everyday culture: epochal not only for German history, but for modern history as a whole. Refrigerators, washing machines, ready meals from the freezer, self-service stores, disposable products, birth control pills, daily showers, trips to the Mediterranean, pizzerias, rock music, discotheques with wild individual dancing: a new lifestyle developed from all these props. Television, initially frowned upon in educated German circles as the "screen" and the subject of fierce cultural-critical controversy, dominated and leveled leisure habits far more than all previous innovations had failed to do. As leisure increasingly determined self-confidence, such leveling contributed to the impression of a "classless society". In 1948, Sigfried Giedion had wistfully dreamed that the mechanization of everyday life would ultimately also lead to the improved resurrection of the "regeneration baths", part of this dream came true in the 1960s with the spread of saunas, which developed into comfortable "sauna worlds"; the nudity taboo, which had already been challenged by life reformers around 1900, crumbled in both German states more than in most other countries in the world. But the technical manipulation of organic matter, Giedion's most shocking form of mechanization, which at the time culminated in the slaughterhouses of Chicago, the horror of "Americanism", also became a matter of course in German meat production.

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Figure 38: Electric wooden tub washing machine with power wringer from around 1950. The tub is made of oak, the base is made of pitch pine, the wringer is mounted on a pine frame: even electrification did not bring about the end of the "wooden age" immediately and everywhere! As wood does not rust or corrode, wooden tub washing machines were considered indestructible. However, they could not be heated; the laundry still had to be boiled in the boiler and then transferred hot into the machine. The "washing day" was still part of the housewife's weekly routine. The model shown, which looks archaic today, was the best-selling Miele washing machine until 1950.

Since the late 1950s, *agriculture* in particular, more than any other major sector of the economy, has undergone a technical and industrial upheaval to which the term "revolution" applies, even though this upheaval received little public attention for a long time, and observations about the alleged "second industrial revolution" generally referred to economic sectors that were far less shaken. In the 1970s, the capital employed per job in German agriculture was higher than in industry! In the fifties, mechanization concentrated on arable farming in continuation of older trends; the tractor replaced draught animals and the combine harvester made many farms deserted. Before the war, chemical fertilizer was spread by hand in piles, but now it was spread mechanically on the fields by the ton. As the sixties and seventies showed, mechanization in livestock farming could be taken even further than in arable farming. After 1960, the number of chickens in southern Oldenburg soared; the GDR hit "Unsere LPG hat hundert Gänse" ("Our LPG has a hundred geese") became a laughing stock in the West. In poultry "production", the dynamic growth in size was almost unlimited; factory-like facilities with hundreds of thousands of animals were built in a short space of time, following the Dutch model. While in the 1950s the waves of indignation over the collectivization of agriculture in the GDR were rippling, German agriculture subsequently experienced concentration processes that were no less merciless for many of those affected. However, the industrialization level of Dutch agriculture was generally not reached. In the eight

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In the 1920s, the mere prospect of introducing genetic engineering methods in breeding aroused widespread opposition.

In *forestry*, there were temporary experiments with large timber harvesting machines of North American and Scandinavian provenance; however, it was recognized that these had a ruinous effect on German forest soils. Until recently, the one-man chainsaw was the form of mechanization adapted to German forest conditions and became the biggest German export hit in forestry technology.[5] The growth of the world's largest consumer of mass-produced small wood, the pulp industry, was slowed down in the Federal Republic by environmental regulations. The furniture industry switched to mass production in the 1960s, but has been particularly hard hit by the mass production crisis since the end of the 1970s.

Since the 1960s, industry has been dominated by a fundamental preference for technologies that reduce the wage component of the product. Arguments of this kind were used to claim a fundamental advantage of nuclear energy over coal at a time when even halfway accurate cost accounting was not yet possible. In the past, mechanization at any price was considered typically American in Europe; the more full employment and rising wages appeared to be a permanent condition, the more a similar entrepreneurial mentality prevailed in the Federal Republic of Germany, especially since the construction of the Berlin Wall in 1961 cut off the influx of skilled workers from the GDR.

Instead, the increased recruitment of workers from southern and south-eastern Europe began, who, unlike the GDR refugees, were generally unskilled. The proportion of foreign workers in the Federal Republic increased fivefold during the 1960s, from two to ten percent, and continued to grow despite the recruitment ban imposed after the 1973 oil crisis. As in the USA, a new underclass of workers strongly influenced by immigrants emerged. While a core of skilled workers had previously been retained in those industrial sectors that had developed a specifically German variety of standardized mass production, this new potential workforce favoured mechanization strategies that, in a departure from German traditions, were calculated for unskilled and highly regulated workers and had previously characterized the USA. In engine production at the Cologne Ford plant, the proportion of foreign workers had already reached 70 percent by 1965. From the later perspective of a spokesman for IG Metall, "many of the American 'deadly sins' were also adopted with the American machine tools in the 1960s". It was only now that parts of the West German car industry reached a "Fordist" level of rigid mass production; beyond the assembly line, the

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new "transfer lines", which Renault had already introduced in 1947, various work processes on a workpiece were connected in series.[6] But it was precisely "Fordist" jobs fell victim most easily to the automation push of the subsequent period, which exploited the opportunities offered by microelectronics. This is one of the main reasons for the rise in unemployment since the 1970s, which affected immigrants disproportionately.

In the 1950s, the dynamics of consumer needs became a driving force of industrial development like never before in history. The enormous pent-up demand concealed the latent tension between technical development and human needs for some time. However, precisely because the consumer frenzy was lived out to an unprecedented extent, the heavily stimulated engine of industrial growth ultimately came up against the limits of the domestic market.

Industry reacted differently to the new situation. While during the reconstruction phase, when the general hunger for goods seemed limitless, production was geared towards the available and easily procurable machines, market research and the development of new markets gained in importance from the end of the 1950s, when the market changed from a seller's to a buyer's market. But government and armaments orders also became more interesting again; the export of goods and ultimately capital reached unprecedented levels. The business world became more complex; companies relied less and less on their own experience alone: thus began the rise of consulting - an extremely characteristic process of the latest era, but one that has only been researched in detail. New paths of mechanization outside of mass production and in the service sector - the largest growth sector since the 1970s - had to be explored.

To speak of a general crisis in mass production would be going too far; but since the 1970s at the latest, an expansion of mass production has generally no longer been a suitable strategy for further growth. This applies in exemplary fashion to the flagship of the German economy: the car industry. As prosperity grew, customers' wishes became increasingly differentiated. Henry Ford's famous saying "The customer can have the color he wants, provided he wants black" became the epitome of outdated productivism, which inevitably led to the crisis. Since then, the modular principle has prevailed in car production: Basic elements of the car continued to be mass-produced, but differentiated in design.

The confrontation with the limits of mass production and the human needs that can be satisfied by goods in general is a common denominator of many recent technology and marketing trends, especially as the waste disposal crisis also marks this limit. Precisely because of this,

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As technology became omnipresent in our lives, the impetus that technological progress received from life's needs diminished. Although there were still plenty of unfulfilled desires, these were increasingly directed towards services and non-mass products that emphasized individuality. Mind you, all this with one major exception: microelectronics, whose products gave rise to a new consumer frenzy. But this frenzy was also followed by disillusionment: The collapse of large parts of the *"new economy"* from 2001 onwards made it clear that the boom driven by the Internet was historically unique and could not be repeated at will - any more than the German "economic miracle" of the 1950s.

Another key process was the growing, ultimately extremely high level of international integration of the German economy, as important impulses for technical innovations always came from foreign trade. After 1945, this was even more true than before, as from then on the dynamics of international trade were primarily determined by trade relations between highly industrialized countries, whereas previously the exchange of goods between industrial and agricultural countries was considered the ideal and typical form of trade. The economic mentality that emerged in West Germany soon after 1945 differed particularly sharply from the principles of the war and interwar period in the extent to which it was export-oriented; Knut Borchardt has spoken of a formal "export ideology". The prevailing economic doctrine lacked the standards for limiting dependence on exports; for Ludwig Erhard, the forced foreign exchange economy was "the symbol of all evil" and trade barriers embodied the "curse of the past", while the wider world was "full of immeasurable opportunities" for the German economy. The export orientation that resulted from the weakness of the domestic market in the first post-war period became a permanent condition, even when the domestic market grew explosively. From the beginning until today, an increase in exports has always been regarded as a measure of success in the Federal Republic and even a slight decline in exports as a cause for alarm. While the total turnover of German industry increased fivefold from the 1950s to the 1970s, foreign turnover increased almost tenfold.

Germany became the largest exporter in the world; in the 1980s, one third of industrial production was exported, leaving even the Japanese, the spectacular climbers of the global economy at the time, far behind. Despite all reservations, the obsession with exports is still on the rise, as the German domestic market with its signs of saturation is not all that attractive for growth strategists, with long-term forecasts showing almost "catastrophic features". The construction sector is often used as a yardstick. In the eighties

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the value of renovating old buildings exceeded that of new buildings: This new trend, which did much to beautify cities but had to be enforced in part against the construction industry, created enough work but not ambitious prospects for technical progress.[7]

In the 1950s and 1960s, the undervaluation of the Deutschmark gave West German industry an effortless export advantage. Since the undervaluation of the Deutschmark both promoted exports and inhibited imports, the fight against the revaluation united former free trade and protective tariff supporters. The liberalization of the dollar exchange rate in 1971 changed the situation; the competitive conditions became tougher. Industrialization progress in some Third World countries worked in the same direction. Protectionist countermeasures were strongly frowned upon in the Federal Republic; only a leading global position in technological progress could protect the German economy from crisis and decline - this became a creed that was repeated over and over again. The rhetoric of "globalization", which has been rampant everywhere since the 1990s, took this trend to the extreme. The extreme dependence on exports made the relationship to technological progress obsessive and nervous. "High tech" as the future of the Federal Republic: this slogan is linked to the idea of an international technology hierarchy in which the production of cheap mass-produced goods is increasingly shifted to low-wage countries. The textile industry, which had once been regarded as particularly "automated", was the first to become a technologically primitive industry destined for relocation to the Third World; the steel industry was subsequently threatened with a similar fate.

If one assumes that industrial development is not based on the global division of labor, but only on domestic demand, this extent of global orientation is not inconceivable. Nuclear energy was the first major German technology to be decisively developed under the auspices of exports and the belief in the global future of cutting-edge technology. The fate of nuclear power exemplifies the problems of the "export ideology" not only in terms of economic policy, but also in terms of technology policy.

The growing international integration of the Federal Republic also had another side that was also important for technical development: the growing internationalization of the capital market. More than ever before, capital seeking investment became a driving force in the implementation of technical innovations, especially since the 1970s, when the majority of existing technologies offered only limited growth opportunities. Since the late sixties, nuclear energy has been promoted not least by the energy industry's need for low-tax clean energy.

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vestment of profits, not by an acute need for energy. The situation has been similar since the 1980s with chemistry's involvement in genetic engineering: a current need that motivated this effort was hardly recognizable; the advantages of genetic engineering methods over conventional methods remained uncertain and difficult to calculate in many cases. The decisive factor for the industrial commitment was the categorical impe- rative of technical innovation in a situation in which previous chemistry only showed a limited ability to develop, and the concern of falling behind the USA and Japan in the technology race.[8]

The sharp break between the period of reconstruction and the subsequent phase, which extends to the present day, is exemplified in Marcel Hepp's 1968 pamphlet against the "Nuclear Non-Proliferation Treaty"; the 32-year-old Hepp was then Franz Josef Strauß' personal advisor and editor of the *Bayern-Kurier*. He evocatively describes how the entire technological development would lose all its glamor and appeal if Germans were to remain excluded from nuclear and rocket technology:

"This orgy of technology, the celebration of computers, the triumph of control technology and the speed of turbines: German industry will never again be able to participate in this in the wake of the lockdown. What remains - to put it drastically - is the perfection of the kitchen, the automation of offices and the refinement of means of transport [...] The technical eros of a top manager or researcher can no longer be bound by the consumer goods production of a quasi-fellachianized industry. The emigration of qualified workers is therefore likely to increase more than before [...] It cannot be the purpose of research to imitate foreign developments in German. Nor can our financial efforts have the purpose of spurring the export of German duodecimal technologists. "[9]

The emotional background and the power dream of the new technology ideology could not have been more clearly revealed, nor could the contrast to the pragmatic attitude to technology in the preceding period have been more stark. Of all things, the technology that brought about the "economic miracle" was treated with contempt, and meeting demand was dismissed as the work of fellows! All the experiences of the "economic miracle" were flatly denied: Nothing more of the fact that entrepreneurial action must be based on the market, on demand, and that in the case of expensive cutting-edge technologies, a head start from abroad can be advantageous according to the motto that one's own stupid heads become wise through Bismarck's experience, while the wise learn from the experience of others.

It was striking enough that the Federal Republic of Germany and Japan, which had no significant arms industry until the 1960s, experienced the steepest economic rise, while the British and French nuclear armaments did not even contribute much to the development of nuclear energy in these countries.

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but was a handicap in the competition with the German nuclear industry: Nevertheless, in politics and journalism, the belief in the
"Spin-off" from cutting-edge military technologies. For some technology euphorics, cost-benefit considerations became petty and trivial. One astrophysicist menacingly predicted that "for fear of anachronism", no one would be allowed to ask the question of why in the future.

However, Hepp was right to the extent that certain directions of technical progress - in particular the drive for technical superlatives at all costs - no longer corresponded to human needs. Even faster and higher missiles, even stronger explosive forces, even harder materials: If such ambitions could still be combined with civilian use in the early 20th century, this is no longer the case with the technical possibilities of the latest era. NATO's "flexible response" strategy, on the other hand, which introduced the principles of flexibility and preparedness for every conceivable eventuality into armaments, created a potentially infinite market for cutting-edge technology. However, the technical superlative sometimes corresponded more to science fiction wars than a real military need, especially as the super projects came at the expense of conventional, tried and tested armaments.

Strauß used to emphasize the *"spin-off"*, the "radiation" of military "high-performance technology" into civilian areas. It is not uncommon to suspect that Bonn's armaments policy was based on the tacit assumption that the Federal Republic could not be defended in an emergency anyway and that armaments therefore had to serve technical progress if they were to have any meaning at all. The secret of the "Starfighter" with its 269 crashes (1960-87) was obviously not the bribery scandals, but the industrial and technological policy motives behind its procurement, which bypassed military and practical requirements: In typical German fashion, an American technology that was specialized for a specific purpose was to be adapted to different situations; the rocket-like aircraft, however, which - "racy, sensitive, vengeful like a diva" - forgave "no human error", resisted adaptation to the geographical and climatic conditions of Central Europe. The (alleged) multi-purpose aircraft MRCA-Tornado, the proverbial "egg-laying wool-milk sow", which in reality was only suitable for a very limited range of tasks, also seems like a caricature of the German strategy of flexibility, which - sensible in itself - did not tolerate any connection with the technical superlative. This armaments project, the most expensive in German history up to that point, ultimately met so few military needs,

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that "MRCA" ("Multi-Role Combat Aircraft") was glossed as "Mili- tary Requirements Come Afterwards" in Air Force casinos.[10]

In 1989, after 17 years as head of the Fraunhofer Institute for Systems and Innovation Research (ISI), Helmar Krupp concluded: "We still have a supply-oriented technology and innovation policy", which, in alliance with large companies but without much consideration for human needs, allowed "technology-push waves to run over the Federal Republic and other countries". The doctrine that the market and consumption were not enough to drive technological progress was not only proclaimed by the CSU and the arms lobby in the 1960s, however, but in a slightly different form at least as much on the opposite side, whether in the SPD or in Der *Spiegel*. At the time, the new technology ideology still had an oppositional streak to some extent; it was combined with criticism of restorative inertia, limited Bonn pragmatism and an excessive reliance on the market and the private sector. In 1968, the German edition of Servan-Schreiber's *American Challenge* was published with a foreword by Franz Josef Strauß. But Strauß's opponents in *Der Spiegel* also sounded the same horn at the time: the Federal Republic was an "underdeveloped country" in terms of modern technology; if the backlog was not made up "as quickly as possible", German workers could earn "only half as much" as Americans and Japanese in 30 years' time. For the supporters of new technologies, the "technological gap" became a dogma; it was already apparent at the time that the "gap" thesis would evaporate if one looked not only at individual cutting-edge technologies, but also made a broader comparison between the USA and the Federal Republic.[11]

The role of industry is ambivalent in all of this. Although rhetorical commitments to state-of-the-art technology were part of good manners, in practice, traditions of cautious adoption of costly innovations continued to have an impact. The company had already had to take enough risks during the war and post-war period. When Ludwig Bölkow praised aviation as a "driving force" at a conference organized by the BDI in 1966, "which carries us all along, [...] that makes the most extreme demands on the technologies required to fulfill the task", he received "special applause"; however, when Daimler-Benz was urged by the German government to take over the "draught horse", the MBB Group, in 1988, the car giant was very hesitant, and when the new Daimler-Benz boss Edgar Reuter, in a decided departure from the wisdom of procrastination, acquired MBB after all, he caused the company to lose billions.

In the nuclear conflict of the 1970s, it became a point of honor for the industry to verbally defend nuclear energy and to declare its support for the breeder reactor and reprocessing as the "closing of the fuel cycle"; in fact, however, the industry was involved in the nuclear projects of the future

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with less and less enthusiasm. In the 1990s, Siemens boss Heinrich von Pierer used to calculate internally that the nuclear business brought the company just two percent of its turnover, but 90 percent of the trouble! In 1985, the Federal Association of Young Entrepreneurs (BJU) even called for the abolition of the Federal Ministry of Research, as its "alleged promotion" of alleged "future technologies" was pointless in view of the unpredictability of the future market - a position that is entirely justifiable in view of history!

In 1987/88, the German government's commitment to space travel was openly criticized in industry and technology circles, the "spin-off" thesis was emphatically denied and the idea that we had to fly to the moon for the sake of Teflon pans was ridiculed. In 1958, the rocket scientist Eugen Sänger was able to announce that the "beginning of space travel" was the "most tremendous historical event in half a million years of human history"; two or three decades later, no one believed that the Soviet
"Sputnik" success would have any significance for the general level of civilian technology. During his visit to the Soviet Union in 1987, when people were talking more openly in the era of perestroika, Franz-Josef Strauß was struck by the fact "that there are two technologies there": a "highly developed military technology" and a civil technology that was lagging far behind. The Soviet Union was the most striking refutation of the spin-off thesis: only many Western observers did not see through this for a long time - or they did not *want to* see it.

The export success of mechanical engineering confirmed the traditional view that a broad base of skilled workers was worth more than high-tech islands. While the pioneers of rationalization at the beginning of the 20th century had wanted to drive out the Wöhlert "Mach-ick" attitude from German machine builders and teach them to educate customers to accept uniform machine types, in 1970 a successful machine builder professed the "philosophy of life": "There is no no", and in 1988 it was recommended to machine tool builders as a recipe for success to learn to produce "even small series profitably" and to "respond more intensively than ever to the wishes of their customers".

When computer technology emerged from this flexibility in the 1970s, it was used in mechanical engineering, albeit only after overcoming considerable difficulties, while the tradition of rigid large-scale production continued in the USA. The recipe for success of Paderborn computer manufacturer Heinz Nixdorf - the "most imaginative and successful entrepreneur in the Federal Republic of Germany" (as former Federal President von Weiz- säcker put it in his 1986 necrology) - consisted of the basic idea of adapting to the problems of medium-sized industry, which was characteristic of Germany and initially had a hard time with this new technology, "not only offering the customer

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simply to sell a computer, but to offer the customer a complete solution, i.e. to focus as far as possible on the actual needs and wishes of the user". None of this pretentious claim to educate the customer! In the sixties, "Mittlere Datentechnik" (MDT) became a special German approach to data processing. Of course, Nixdorf missed out on the gigantic PC business by specializing in medium-sized companies. "I don't build mopeds," he used to reply when asked why he didn't get into the PC business.

Recently, "combi-tech" - the combination of electronics and conventional technology - has become a German specialty. However, there also seems to be a lot of loosely networked coexistence ("Upstairs the IBM computers spit out paper, downstairs the masters are in charge as always."). IT systems were often acquired for reasons of prestige; their actual use did not correspond to the perfect computerization models. Mechanical engineers, fitters, locksmiths, welders - all professions that were at the height of the "digital revolution" were considered old-fashioned - are increasingly being sought again after the turn of the millennium.[12]

2. Adapting the environment to the car

For decades, the automotive industry has been the symbol of the German economy. In the first decade of the Federal Republic, it was not yet that far advanced; in the mid-fifties, the Federal Republic was still far behind not only the USA, but also England and France in terms of motorization. In 1954, an American observer predicted that the Germans would never catch up "unless decisive measures are taken by the state". "Experts therefore fear that the favorable situation that has prevailed in the automotive industry to date will come to an end in the foreseeable future." In the entire 1950s, the German road network was only expanded by six percent. On the roads of the pre-war period, the growing motorization became increasingly agonizing.

"The Federal Republic threatened to literally clog up." The situation was exacerbated by the fact that many Germans, more than Western Europeans, lacked the traffic discipline required by mass motorization; the literature on traffic education that was emerging at the time is teeming with complaints to this effect. The aristocratic era of wild car chasing at the beginning of the century was followed by a plebeian era of motorized jostling. At the beginning of the fifties, twelve times as many people died on German roads as in the USA, relative to the number of kilometers driven!

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As a counter-reaction, there were years of protests; pedestrian associations were founded under the motto: "Pedestrians of all countries, unite!" The general climate of the times did not yet discourage such resistance; after the experiences of the 1920s, the car industry was not regarded as a reliable economic engine. In terms of its tradition, the German car industry had previously been only slightly export-oriented; during the Nazi era, it had been forced into exporting. In 1956, Daimler-Benz still feared the technical superiority of American cars when import tariffs were reduced. But as early as 1959, the USA became the company's most important export country.[13]

As after the First World War, truck traffic had more free rein than ever after the Second World War; the traffic police were instructed from above to carry out generous axle load checks. In 1953-55, Federal Transport Minister Seebohm fought in vain for a "Road Relief Act" to force long-distance truck traffic back onto the railroads. Seebohm's initiative was evidently primarily motivated by fiscal considerations, namely the growing federal railway deficit, and was not based on an alternative transport concept. The opposing side, however, turned it into a question of principle, as the neo-liberals had a fundamental preference for private motorization due to their aversion to the railroad monopoly. Federal Economics Minister Erhard advocated the view that "the transport problem could also only be solved by expansion", i.e. by expanding the road network accordingly. Until 1957, this was opposed by the iron austerity of Finance Minister Schäffer. Schäffer's replacement also marked a turning point in transport policy, which was now able to develop its own momentum. Traditional concepts of a sensible complement to rail, truck and car in accordance with the technical characteristics of these means of transport were overrun by mass motorization.

In 1960, the Bundestag passed a law earmarking the mineral oil tax for road construction: an unusual act that contradicted the principle of the unity of the state budget that had applied since the Prussian reforms and heralded an epochal turning point in the German transport system, as the growing motor vehicle tax revenue now exerted a permanent compulsion to build roads. The fact that the social costs of car traffic were far from being covered by road construction was no longer an issue. "Road construction instead of armaments" was an SPD election slogan at the time. The ADAC led a formal campaign against avenue trees in the 1960s. However, the huge increase in road construction in no way reduced the number of road deaths, but instead encouraged speeding; 1970, the year of the "ecological revolution", saw a sad record of around 20,000 road deaths.

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On the other hand, the profitability of the Bundesbahn deteriorated dramatically from 1960 onwards. Instead of investing in the railroads, the main political trend was towards the construction of freeways and bypasses, while in France, the traditional country of automobilism, the administration resisted the construction of motorways until 1970 and instead made France the pioneer of high-speed trains.[14] Since the 1920s, it had also been undisputed in Germany that the future of the railroads belonged to electric traction; however, the electrification of the Bundesbahn only made major progress from the 1960s onwards. The fact that the British railroad workers' union had managed to ensure that electric locomotives were still driven by a stoker was regarded in Germany as a prime example of a British trade union grotesque; however, the German railroad administration also had a pronounced moment of inertia with its esprit de corps, which was reinforced by the scarcity of investment funds. As a result, Germany lagged behind France and Italy in the modernization of the railroads until the 1970s.

The expansion of the roads influenced German car technology. In the 1950s, the experimental Borgward (Bremen), which still built cars using handcrafted methods, was the darling of car enthusiasts and its Lloyd ("Leukoplastbomber") was the most popular small car, notwithstanding the mocking verse "Wer den Tod nicht scheut/fährt Lloyd" ("Who doesn't shy away from death/drives Lloyd"); but the Borgward bankruptcy in 1961 was a sign of the times. At the time, the VW Group had become the epitome of the "economic miracle", whose "Beetle" - a development project of the interwar period - even surpassed the legendary success of Ford's "Tin Lizzy". In 1970, however, the sales curve of the "Beetle" took a downward turn; Daimler-Benz became the industry leader. Faster cars increasingly shaped the profile of the German car industry. VW boss Nordhoff had threatened to stop supplying one of his authorized dealers with cars when he took part excessively in car races; the classic VW advertisement ("The VW runs - and runs - and runs ...") advertised the reliability of the "Beetle". In 1988, on the other hand, a car advertisement featured a woman with a moist, sensual look: "I don't want a reliable bore. I want turbo temperament."

Unlike VW, Daimler-Benz, as a producer of luxury cars, had long been relatively reluctant to use methods of highly mechanized mass production; in 1973, however, Daimler-Benz became the first German company to successfully use industrial robots.[15] The VW plant, whose long-time boss Nordhoff, like Henry Ford, was proud to have resisted "all temptations to change the model and basic design", had to make efforts to increase the flexibility of its production at the same time. The limits of rigid mass production, which had already become apparent in the USA with Ford's Estate model in 1927

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were also reached in the German car industry around 1970. In the crisis of 1974/75, VW laid off 26 percent of its workforce, but 66 percent of its foreign workers; in the course of flexibilization, a different type of employee was sought than the unskilled "guest worker". In the 1980s, the abolition of the assembly line, the creation of larger work units and a reduction in speed were regarded as "German concepts" by British car manufacturers. Now the "scientization" of car production and of the product itself; electronics found their way into the automobile.

Nevertheless, the history of the car is difficult to place in an innovation-oriented history of technology, but rather sheds light on the need to change the style of technology history in the 20th century. Even though car advertising talked incessantly about innovations, the car remained remarkably rigid in most of its basic technical elements. The best-known example of this conservatism is the fate of the Wankel engine, the rotary engine developed by Felix Wankel together with the NSU company from 1950 onwards, which could have become a German innovation in automotive engineering. In the 1960s, there was a wave of "Wankel euphoria" in both German states, and not only there, which then proved to be - pun intended - fickle. The basic idea was reminiscent of the transition from the piston steam engine to the turbine, where rotation was generated directly and not via the ups and downs of a piston. In 1963, the new NSU Ro80 with its Wankel engine and aerodynamics perfected in the wind tunnel caused a sensation among car enthusiasts - but it was not a sales success. As is so often the case in technology, the devil was in the (not fully developed) detail: theoretically highly energy-efficient, the engine actually had relatively high fuel consumption. It only made automotive history with the introduction of the "crumple zone". The most striking feature of the "Beetle" was not its technology, but its design, and it was above all the changes to the design that brought movement to the car's tinny technical history.[16]

The history of the car is revolutionary not because of the technology, but because of the consequences of mass motorization. In the 1950s, the ideal of the "car-friendly city" began to take effect; with this in mind, West Berlin decided to abolish streetcars as early as 1952, even though the car was least worthwhile in this city, which had become a political island. The architect Reichow, for whom the "car-friendly city" took on visionary traits - he had once propagated the "organic" city and was nicknamed "Prince Bernhard von Organien" - propagated decentralized new housing estates with intersection-free road networks; he attacked the "robot traffic lights" as "dangerous, humiliating people in their dignity".

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time robbers". It was not until the 1960s that these tendencies came to full fruition with a wave of road breakthroughs and urban highways.

But from around 1960, public opinion began to change: The urban planning dogma of segregating residential and industrial districts, which originated in the age of the "smokestack industries", began to falter; the desolate city centers and individual housing estates stretching uniformly into the countryside - once the utopia of the "city in the countryside" - were experienced by more and more people as monotonous. Sennestadt near Bielefeld, Reichow's urban utopia turned to stone in the 1950s, was later regarded as a barren city that the people of Bielefeld avoided. "Urbanity" became the new ideal; however, it was not always easy to realize in a pleasant way.[17] The pedestrian passages - a characteristic innovation of the last decades (first in Kassel in 1961) - removed traffic from the main shopping streets of the city centre, but shifted it all the more into adjacent city zones. Everywhere it became a normal tourist experience that one had to fight one's way to the increasingly polished "historic centers" through vast barren urban areas - until new district initiatives brought about a certain countermovement. At the same time, mass motorization made it possible for many factories to migrate from the cities to the countryside, where there was still plenty of room for expansion and where it was possible to build on a large scale: This became the prerequisite for a systematic reorganization of many manufacturing processes.

3. A new industrial revolution?

The metaphor of technical "development" makes sense: to be precise, all technical "revolutions" have a pronounced element of *evolution*. And yet there is, to use the Hegelian-Marxist jargon, a "transformation of quantity into quality", which is often more drastic in technology than in economic statistics. The railroads, large power stations, automobiles and airplanes were *not* just continuations of a continuous development: they represented a leap in development. It is difficult to decide whether an account of the last half century of German technological history should focus on continuity or change. If a "second industrial revolution" has been claimed again and again since the 1950s - for example through "atom and automation" - it is quite clear that for decades this term went far beyond what was actually happening. Nuclear energy did not create a new era in the positive sense of the word, nor did it bring about the "second industrial revolution" that Robert Jungk perhorres-

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nuclear state". Significantly, the "atomic age" was most talked about in the 1950s and early 1960s, when the "peaceful atom" was still virtually non-existent as a reality. The new era of automation was also most talked about at that time, when in reality no radical revolution in production technology had yet taken place. Since the 1950s, new technologies have given rise to new production structures to an astonishingly small extent, although there has never been as much talk of "system" and "innovation" in the technical literature as in recent times. Despite all predictions, nuclear power was completely absorbed into the existing energy economy and largely incorporated into the traditions of power plant technology. From the very beginning, genetic engineering in Germany was predominantly the domain of the established chemical and pharmaceutical industries. Even electronics, albeit after some turbulence, was by and large integrated into the electrical and mechanical engineering industries; the "new economy" that it had brought about was largely only temporary. And yet, after it was thought that the "electronic age" was a word bubble similar to the "nuclear age", something revolutionary has actually happened on an electronic basis: There is no longer any doubt about this today. Much of this happened silently at a time when the debates about "automation" and the "second (or third) industrial revolution" in the trade union world had fallen silent.

In many, though by no means all cases, it was more about new process elements than new products. If the distinction once made by Emil Lederer during the Great Depression between process innovations that save people and product innovations that create employment seemed to lose its significance in the post-war period, as process and product innovations partially overlapped, this difference regained importance. Lederer's theory of technologically induced unemployment, which for decades had seemed to belong in economic mothballs, regained an uncanny power of persuasion, even if economic theory had long thought itself superior to such concrete thinking. In 2004, Hans-Jürgen Warnecke, a highly experienced head of research and company board member, criticized the still widespread belief that innovations - of whatever kind - are a patent remedy for creating jobs: "Until the middle of the last century, innovations actually created prosperity and jobs [...] Today's innovations also create jobs in their own area of production, but in their areas of application they reduce or even eliminate jobs." The 1950s as a watershed in the history of technology, at least from a labor perspective!

If steel is seen as the basis of German industrialization, a change in times manifests itself above all in the steel crisis. It is not

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Similar to the seventies of the 19th century and the twenties of the 20th century, rationalization associated with capacity growth contributed to the vulnerability of mass steel to crises, while special steels held their own. The rationality of size growth in heavy industry became more questionable than ever before; flexible and specialized "mini steelworks" survived the crisis far better than the
"Steel giants". Although the Federal Republic of Germany became the world leader in per capita consumption of plastics in the 1960s, the replacement of steel by plastics that has been predicted for half a century has not materialized. Even proclamations of an age of "new materials" are mainly of an advertising nature. Last but not least, the post-1970 eco-era with the renaissance of recycling has put a damper on such visions of the future and brought the old, perfectly recyclable materials back into favor. There were just as few revolutionary upheavals in the range of professions. A careers advice brochure published in 1973 stated:

"The opinion sometimes expressed that a large number of new professions will emerge as technical development progresses has not yet been confirmed [...] Judging by the numerical demand, it is not electronics technicians, measurement and control technicians, nuclear physicists and systems analysts that will be the professions of the future, but rather, for example, locksmiths, mechanics, concrete workers and bricklayers. "[18]

In 1970, the share of crafts in the secondary sector was almost as high as in 1950 (35 and 36 percent). However, as the skilled trades are not considered to have much of a future and the computerized image of progress includes a devaluation of manual skills, the skilled trades are worried about recruiting new talent even in a time of mass unemployment. At the same time, it was discovered time and again that the emergence of new professions proceeded far more slowly than would have been expected based on dramatic notions of secular technical change.

From the beginning of the century until the 1960s, there was talk of "automation" and, from the 1950s onwards, much talk of "robots", without the manual control of machines really being eliminated in most cases. What "automation" meant in concrete and technical terms often remained unclear; erroneous assumptions about the reality of operations - the typical educated cliché of the worker as a dull-witted "cog in the machine" - were also frequently involved when talking about "automation". The groundbreaking study by Kern and Schumann (1970) found that "automation" almost always involved partial automation of very different kinds. At that time, the majority of workers had little concern about future automation prospects: experience seemed to show that workers retained their "expert role as practitioners" in rationalization processes.

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The trade unions had been involved as partners in *ratio- nalization protection agreements* since the 1960s; they saw rationalization - similar to the good years of the Weimar Republic - as an opportunity rather than a threat, especially as economic growth compensated for the redundancy of workers caused by mechanization until the early 1970s. Former Schlesinger student and radar technician Leo Brandt, a leading technology expert for the SPD in the 1950s and a passionate advocate of nuclear technology, even expressed the concern at the time that the Germans could fall behind other nations in terms of "automation". Günter Friedrichs, head of the Automation and Nuclear Energy department at IG Metall, recalled in 1968 how he had "kept the works council busy for two years" before the Borgward bankruptcy "in order to get the old Borgward to rationalize and automate its production".

In 1965, IG Metall organized what was said to be the largest international conference on the "risks and opportunities" of automation in Oberhausen - the The "risk and opportunity" counterpoint replaced the "curse or blessing" formula of the 1950s when discussing new technologies - but the trade union chairman Otto Brenner described the topic of the conference as a concession to the "automation buzzword that had become popular". For the trade unions, what "automation" meant in concrete terms at the time had long been an undramatic, everyday process that they believed they had under control. In fact, the automation processes of the time predominantly concerned the areas of rigid mass production; the limits of this type of "automation" could be recognized. From today's perspective, however, real automation had barely begun. The trade unionist and former technology minister Hans Matthöfer admits today that the biggest mistake of his life was the belief that automation would bring about social revolution![19]

Even in industrial circles in the 1960s, people imagined that they were already at the height of the "age of electronics". With about
3,000 computers, Germany was in second place behind the USA in 1966. The big turning point came after 1970 with microelectronics, which initially took the Federal Republic of Germany by surprise, where the idea of giant machines had been associated with electronic computers for too long. From 1970 to 1979, the number of computer systems in the Federal Republic rose from 7,260 to around 180,000, and that was just the beginning.[20]

Is "revolution" the appropriate term in this case? A definitive answer to this question is not possible at present. From a purely physical and technical point of view, microelectronics is a "completely different and qualitatively new technology" compared to earlier technologies - at least according to semiconductor researcher Hans Queisser. However, the use of electronics to date

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largely along the lines of rationalization that have been pursued for a long time. In principle, the new technology offers opportunities for decentralization; in practice, however, it makes it possible to continue the trend towards networked large-scale organization beyond a point where it would otherwise have been slowed down by the increasing organizational complexity: In this respect, electronics has a conservative rather than revolutionary effect.

As Weizenbaum complains, the main interest of the "compulsive programmer" is "not in small programs, but in huge, ambitious program systems". The highest stage of computerization, "computer-integrated manufacturing" (CIM), corresponds as a target perspective to a situation in which "the technical opportunities for rationalization appear to have been exhausted" and only further networking of planning, design, production, quality control, warehousing and sales promises further advantages. In this respect, "CIM" was more of an end than a beginning from a purely technical-historical perspective.[21]

Genetic engineering has been a comparable case since the 1980s. On the one hand, it is claimed that the new molecular biology relates to classical biology "like a jet turbine to a single-cylinder steam engine"; compared to natural protein production in cattle on pasture, the new means can - theoretically! - to a hundred thousand times and much more. From curing cancer to solving energy and environmental problems, there is hardly anything today that is not attributed to genetic engineering as a future possibility. De facto, however, the benefits of this new technology, at least in Germany, have so far mainly consisted in the fact that a number of existing pharmaceuticals can be produced using a different, not always cheaper, process.

There is no talk of a "revolution".[22]

Although the "new technologies" particularly affect the organization of the production process, they have not brought about any dramatic changes there either; recent studies in the sociology of work show that it has apparently been possible to "integrate the new technologies into the existing work organization structures". In 1989, the industrial sociologist Gert Schmidt summed up: Despite many proclamations to the contrary, "the process of the so-called third or fourth technical-industrial revolution is taking place surprisingly slowly if one tries to grasp it at the organizational level". A kind of "technical revolution" has at least taken place in the Federal Criminal Police Office, where under the presidency of Horst Herold (1971-81), driven by the fear of terrorists, the permanent computer-aided evaluation of all criminal files was introduced: a rationalization of a questionable nature, as it multiplied the number of suspects and thus the number of cases to be processed enormously.[23]

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In 1986, BDI President Langmann noted that the "so-called high-tech sector" currently accounted for just "five percent of the production value of industry", albeit with an upward trend. A "return-on-management" study in 1987 led to the "surprising realization" that "there is no evidence that information technology has an influence on business success". In general, the rule seems to be that computerization is relatively easy to implement where it affects workers' activities, but much more difficult where management competencies are affected. The computer as such does not eliminate power structures. It follows that computer control only functions as an individual component, but not as a supersystem, as it is so often misunderstood.

According to an industry expert in 1988, most companies have so far failed to introduce an IT-supported production organization.
"Castles in the air of automated factories crumble into desolate ruins. "[24] Many experiences with the introduction of "modern office communication systems", which are often credited with breaking down the division of labor, were not much better; in practice, "chaos and frustration are the order of the day"; "the crash of systems paralyzes entire office landscapes". It is no wonder that while the German Federal Post Office launched a 300 billion project (ISDN, Integrated Services Digital Network) to network various communication technologies with fiber optic cabling, which will run until 2020, the habits of the office environment showed "enormous inertia" towards the new technical offerings, especially towards technology concepts that understand progress as the equalization of communication.
"New communication systems" of the recent past such as Btx and Teletex were an economic failure; the services offered by ISDN were not in demand to the extent expected.[25]

The human-like, mobile and sensor-equipped robots that have been haunting science fiction literature for decades are still few and far between in industrial reality, and there is no sign of a rapid growth trend. We had to learn that even the smoothing of furniture parts, which every human can learn in a short time, cannot be taught to robots "with reasonable effort". After a lengthy discussion and expert hearing on artificial intelligence (AI), the Bundestag's Technology Assessment Committee came to the remarkable conclusion that it had not found a clear answer to the "first question - what is AI? - no clear answer was found", although AI has also had its community for decades. The lack of clarity about what buzzwords actually mean is characteristic of the reception of new technologies in general and characterizes the discussion about electronics to a greater extent, where

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Information, information storage, measurement, computing and control technology are blurring into one another.[26]

Nevertheless, the rapid expansion of microelectronics is obviously associated with far-reaching changes: Changes for which the terms are still missing in some cases, such as the technical possibilities of flexibilization. While flexibility in manufacturing has traditionally meant a higher proportion of manual work and a slower pace of production, microelectronics makes it possible to a certain extent to combine flexibility with highly mechanized mass production. In the past, progress in terms of increasing the degree of mechanization and efficiency led from universal to special machines and thus to an increase in the size of production units, but this rule now only applies to a limited extent. Kern and Schumann note in 1984, similar to Piore and Sabel in the USA, a

"new rationalization paradigm": "efficiency through flexibility". The basic principle itself is not new; the insight that even in mechanized mass production, attention must be paid to flexible alignment with demand runs through the entire history of German industry; but until recently, it was difficult to translate this insight into a technical rationalization strategy.

However, programmed flexibility also remains - how could it be otherwise? - diversification within the scope of certain possibilities; outside this area, the rigidity of production tends to increase, as far as can be seen so far. The "flexible production system" "requires a degree of planning security for its effective use that the majority of machine tool companies cannot hope for in the future for their own production".[27] Collisions ("interfaces") with non-computerized areas arise both inside and outside the company. The old dilemma of productivism, that the perfection of a particular production system makes a company more vulnerable to changes in external conditions, does not seem to have found a definitive technical solution even with electronics. Assembly Hall 54, which was opened by VW in the fall of 1983 and soon became world-famous, with its 80 robots - at the time the most modern assembly hall in the automotive industry anywhere in the world - was still tied to a specific type with its rigid interlinking: the new "Golf", which repeated the success of the "Beetle" for quite some time. The major problem was "the almost unmanageable complexity of the technology, which led to frequent production breakdowns and high production losses, especially in the beginning" (Thomas Haipeter). Even the new information technology did not prove to be the hoped-for *deus ex machina*. In the meantime, advances in electronic control have improved the chances of combining a high degree of automation and flexibility, but the rule still applies: "People are and remain the most flexible."

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The extent to which technology itself has become more flexible is partly a question of perspective; however, it is very clear that the technical development of the new era demands increased flexibility from people: through technically induced job losses and retraining constraints, through changes in the nature of work and through the progressive flexibilization of working time, which increasingly calls into question the once hard-won freedom to work at weekends. In this respect, the element of continuity in recent decades should not be overemphasized. Not only the thesis of the second (or third) industrial revolution, but also the criticism of it was partly interest-driven: If the trade unions and works councils had already foreseen in the 1960s the extent to which the new wave of automation would destroy jobs, the issue of "automation" would probably have been dealt with differently than it was at the time. Although there was always talk of the active involvement of employee representatives in the public discourse on rationalization, one does not get the impression that this had a significant impact on the actual course of events. The rationalization

The "re-professionalization" of industrial work predicted by the "high tech" has partly taken place - unskilled workers have become increasingly difficult to place in recent decades -; however, this new individualistic type of skilled worker is often alien to the trade unions.

VDU workstations represent a deep and secular break in the sensual side of industrial work. The emotional relationship between workers and machines has diminished; it would also be a hindrance given the frequent changes in computer technology. The identification with work that was long considered "typically German" has declined considerably over the last few decades and can now only be found in a fraction of employees. This observation is not in itself judgmental; the facts do not necessarily indicate a loss, but could also indicate a gain in the art of living. Incidentally, if we look back at all the processes of habitualization in the course of the history of technology, it comes as no surprise that new forms of personal experience and identification with work, including self-exploitation, also emerge on screens under suitable conditions. Nevertheless, the historical facts do not support any straightforward analogies to the past. The enormous facilitation and multiplication of technical communication has its flip side: expectations of people's ability and speed of communication have also grown colossally. How people deal with these expectations: This story is still open today. Whether it is a "technical revolution" or not, a profound change has taken place in recent decades in man's technical approach to the outside world and his own nature.

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probably of a radical nature that goes beyond all the processes of change brought about by industrialization up to that point.[28]

4. Nuclear energy between technological visions and the energy industry: German, European and American technological paths in nuclear technology

Nuclear power was the first technology to be developed with extensive state funding, without even a remotely visible need that would have matched this expenditure. Although there was talk of an "energy gap" in the early 1950s, when the post-war coal shortage still recurred periodically, the overriding problem of West German energy policy was the oversupply of coal when things got serious with reactor construction. The need for historical explanation is even greater for the genesis of nuclear technology than for most older technologies.

This was followed by other "new technologies", typically imported from the USA, whose practical value was difficult to overlook and which demanded state funding. For the federal government, these were a means of asserting federal competence for science policy vis-à-vis the federal states. The Ministry of Science, Research and Technology emerged from the Federal Ministry for Nuclear Affairs. The nuclear research centers became the forerunners of a new type of research that was detached from the universities.

"Big Science", which, following the American model, sought to make large-scale technical facilities the crystallization core of science and, in part, operated a "large-scale production of relatively simple information" (Cartellieri) reminiscent of industrial conditions, but increasingly became an intellectual "mixed goods store". However, nuclear energy made its mark on the history of German technology primarily through the controversy it triggered. Nuclear technology was certainly epochal and forward-looking, but in a different way than people thought in the 1950s.

In the 1950s, the necessity of German involvement in nuclear technology was generally taken for granted; the only disputes were the speed, the role of the state and the types of reactor to be preferred. Only much later did the thought arise as to whether other paths of technical progress would not have been more advantageous. For the electrical industry, which took the lead in reactor construction, the alternative would have been electronics, the technology that the Japanese electrical industry favored in exchange for

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foregoing its own reactor development. In Germany, too

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In the 1950s, there was much talk of "electronic brains", although the first disillusionment came earlier than with nuclear power. The supposed new age was often defined not only by the atom, but also by automation.

Why was it unthinkable for the leading electrical companies at the time to concentrate on electronics instead of nuclear technology, as the Japanese electrical industry was doing at the time, despite highly developed electron tube production? One explanation can be found not only in global trends, but also in the ingrained German engineering mentality: the idea of performance, competence and solidity trained in mechanical engineering. It is no coincidence that the development potential of the small transistor received little attention in Germany. In electronics, large-scale industry was fixated on large computers, but their sales opportunities seemed slim in a country without a high level of technical sophistication. The fact that there was rapid progress towards miniaturization was initially hardly noticed in the Federal Republic.

Competition for electrical consumer goods became increasingly fierce after 1960; they offered less and less enticing growth prospects. Large-scale projects that promised monopoly positions came in handy here as a counterweight and generally fitted in better with the Siemens and AEG tradition. Within electronics, it was German tradition to initially devote the main work to the "hardware", the apparatus. The development of the "software", the programs, was not initially recognized as a highly developable area of its own; the type of software engineer seemed unsound to German mechanical engineers for a long time. In addition, the software boom started with computer games of all things, which simply seemed silly to engineers with a pride in science - and not only in Germany. Even the established companies were slow to realize how much money could be made with these gimmicks.[29] Just as the PC boom was beginning around 1990, Siemens dissolved its own software departments and awarded contracts to small suppliers. German industry had at least as great an opportunity with software, which had to be geared to specific customer needs, as it did with hardware, as the success of Nixdorf shows.

In the history of the development of the German nuclear industry, the initiative initially lay more with the chemical industry than with the electrical industry, let alone the energy industry. At the time, there was often talk of radioactive substances revolutionizing the entire chemical production process, but it is doubtful whether the industry itself believed in this "revolution". Chemistry would have become a key nuclear industry primarily through reprocessing. In fact, plutonium production was a high priority in Bonn's nuclear policy, even without any civilian use of the nuclear fuel.

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plutonium would have been secured. The Swiss chemical industry, otherwise comparable to the German one in many respects, showed much less interest in nuclear technology: The comparison with Switzerland highlights the power-political impact of German nuclear policy, even if this was not allowed to be expressed openly and in plain language. Häfele, the head of the breeder reactor project, proclaimed with suggestive rhetoric in the 1960s that large-scale technical projects were part of the "assertion of a nation" even "if the price to be paid for them became fantastic"; they would "lead to political substance" in the Federal Republic.[30]

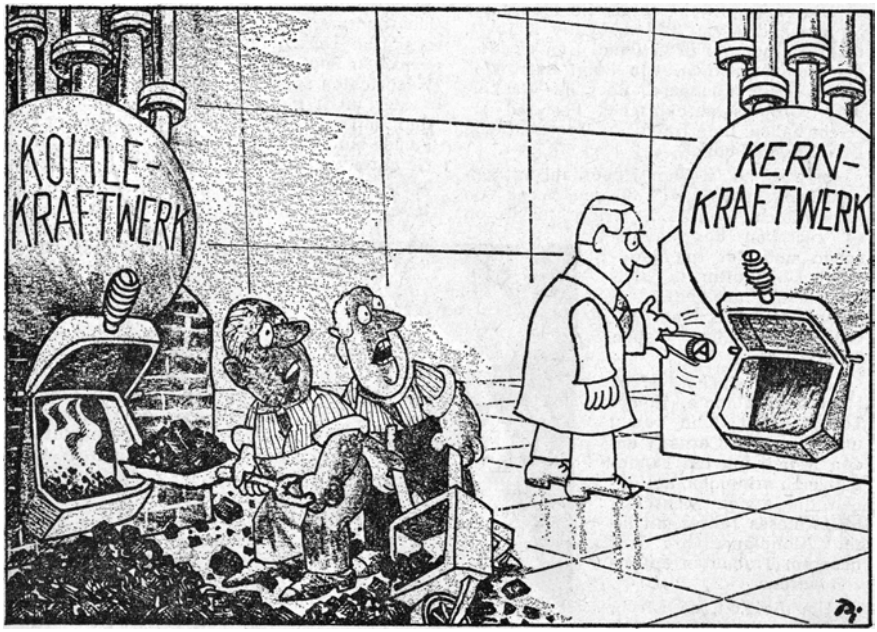

Figure 39: "Man, they're taking the pill now": Caricature from the *Industriekurier in* 1969, when the first German order boom for nuclear power plants began, but most Germans still had no concrete idea what nuclear power plants were. The nuclear reactor, which bears little resemblance to a real reactor, looks like the furnace and steam boiler of a coal-fired power station. The stark difference lies in the tiny amount of fissile material required and the external cleanliness of the nuclear power plant - and the "white-collar" worker who operates it. In the 1960s, "the pill" was the "birth control pill"; when people said of a girl: "She's taking the pill now!", it aroused fantasies of sexual uninhibitedness. Nuclear technology also had a "sex appeal" in the figurative sense, especially for "progressive" people at the time!

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If you want to apply Max Weber's concept of charisma to technology, nuclear technology is a prime example: both for the power and for the crazy aspects as well as for the transience of charisma. There was a pronounced coherence among those involved in the development of nuclear energy from the very beginning; those who belonged to it put their heart and soul into it. The *community* or even "family" of experts became a standing concept here (a generation later it would have been called a "network").

As elsewhere, nuclear physicists were the driving force behind the beginnings of nuclear policy in the Federal Republic of Germany, especially the circle around Werner Heisenberg. The need to further utilize the expertise acquired in the nuclear project of the Second World War and to demonstrate the civilian benefits of nuclear physics, which had been tainted by Hiroshima, as quickly and impressively as possible, put leading German nuclear scientists in a state of impatience. However, it is doubtful whether nuclear energy proves the effectiveness of the "spin-off" of military technology. Rather, the history of nuclear technology, like that of computer technology, could demonstrate how a new technology is burdened by its military origins with problems with which it would otherwise presumably not be afflicted to the same extent.

Some of the problems resulted from the slower pace caused by the armaments. If the development of nuclear technology had taken generations, similar to that of the steam engine - and this would probably have been the case without military pressure - it would in all likelihood have been much less conflict-ridden; there would have been enough time to test different reactor concepts, wait for experience to be gained and keep the risks low by keeping the plant dimensions small. In reactor research and industry circles, the view is widespread that the process was slow and cautious enough; however, against the background of the older history of technology, one can recognize the impatience with which reactor development was driven forward. During the nuclear euphoria of the 1950s, Friedrich Münzinger, an experienced construction manager of large power plants, warned against accelerating the pace of nuclear energy development, while Werner Heissenberg, the luminary of German nuclear physics - who, however, was not responsible for any power plants and understood nothing of the technical details of nuclear power plants anyway - was already impatiently pushing for reactor construction in Bonn in the early 1950s. In 1962, Federal Minister Balke, who came from the chemical industry, snubbed the nuclear pushers before the responsible Bundestag committee with the rebuke that there was no need for nuclear energy in the Federal Republic for the time being - at best "in the Arctic, in the Antarctic or on the oceanic islands" there might be sensible locations for nuclear power plants!

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German nuclear policy in the early days favored the heavy water reactor, the reactor concept inherited from the wartime nuclear project, whose attraction for the military was the high plutonium yield and for nuclear physicists the good neutron economy. However, this approach to reactor development was overrun by the victory of the American light water reactors in the 1960s. From then on, the high-temperature reactor (HTR) was often regarded as a specifically "German" approach, although the concept originated in England; in the seventies, construction of this type of reactor only continued in the Federal Republic of Germany. High temperatures, which enabled higher efficiency and the use of process heat, made "every engineer's heart beat faster", as the long-standing project manager Schulten emphasized; the light water reactor (LWR), on the other hand, forced a departure from this traditional engineering preference. But it was precisely the LWR that became the recipe for success for the German nuclear industry in the 1960s; the Federal Republic led the way in Europe with the construction of light water reactors. The implementation of this type of reactor was a victory for the economists over the technicians and at the same time for the admirers of the USA over the advocates of Germany's own profile in nuclear technology.[31]

In the century-long German confrontation with American technology - this eternal ambivalence of imitation and jealous demarcation - nuclear policy represents a culmination. In 1964, Karl Wirtz (Karlsruhe Nuclear Research Center), as spokesman for the Nuclear Reactors Working Group in the German Atomic Commission, declared that the entire German reactor development had to be seen "exclusively from the point of view of competition between German industry and American industry on the world market".[32] Particularly in its first decade, Bonn's nuclear policy was concerned with distinguishing itself from the USA with its own reactor lines, which were in some way characterized by better efficiency and by guaranteeing the highest possible German fissile material self-sufficiency. Hence the preference for high temperatures, optimum neutron economy, breeder properties and natural uranium, which meant independence from American uranium enrichment plants and was the hallmark of a "nationally" accentuated reactor policy in all countries with nuclear ambitions at the time.

However, RWE and AEG, which was affiliated with General Electric, showed an early preference for cheaper American light water reactors. The breakthrough of this type of reactor changed strategic thinking in German expert circles: Soon, the latest reports from the USA were regarded as insider tips; this was particularly evident in breeder reactor development. However, AEG, which had completely taken over the boiling water reactor from General Electric, ultimately failed in nuclear technology.

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The company had not built up enough nuclear expertise of its own to be able to cope when no American know-how was available, and this was all the more fatal as the boiling water type at the time, although tested for the longest time, was ultimately defeated by the pressurized water reactor due to technical defects. Siemens, the original promoter of the heavy water reactor, took over the pressurized water type from Westing House, but emancipated itself from its American partner as soon as possible. The contrast in the behavior of the two companies towards the USA is reminiscent of the early days of "Kraftstrom" in the 1880s.

Several problems were ignored when imitating the USA. The United States was a nuclear power; the civilian reactor types were chosen to benefit from the military uranium and plutonium plants; a fluid border to military technology was one of the basic conditions of reactor development. If the Federal Republic of Germany had seen itself definitively and for all time as a non-nuclear power, it would have been obvious to examine the suitability of American reactor technology. On top of this, the "safety philosophy" in the USA - although not unchallenged - was that one had to expect the worst and therefore nuclear power plants should only be built in sparsely populated, easily evacuated areas; because the light water reactors had a lower inherent safety than other reactor types discussed in the early days. The Germans could not follow the Americans in the "philosophy of safety distance", as there would hardly have been any reactor sites in the densely populated Federal Republic under this assumption. In order to make a virtue out of necessity, German nuclear circles developed the ambition at the end of the 1960s to lead the way worldwide with the construction of a nuclear power plant close to a large city (near Ludwigshafen, at times also near Frankfurt), which would also supply the chemical industry with process heat, thus demonstrating the particular reliability of German reactors. But even Wirtz was appalled by this project and, together with RWE, which did not want any competition for Biblis, helped to thwart it.

The proposal to build nuclear power plants underground came up again and again: This concept, a logical consequence of dispensing with a "safety distance", even gained prominent support, but was regularly brushed aside again by the industry. In 1981, the Siemens-dominated Kraftwerks-Union (KWU), which at the time had gained a de facto monopoly on the construction of nuclear power plants in Germany, threatened to stop building nuclear power plants if the licensing authority insisted on even one prototype for testing underground construction![33]

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While the traditional German-American competition in cars and machines was a real competition, the race in nuclear technology had something imaginary about it. Around 1964, the announcement that the American industry would bring fast breeder reactors onto the market at fixed prices in ten years was used in Karlsruhe as an argument for a hasty leap to breeder reactor prototypes; even then, the announcement was not exactly credible. Around 1968, the reference to the USA was used as an argument for the controversial decision to concentrate all efforts on the sodium breeder and to drop the steam breeder; even then, a closer look at the American scene could just as easily have called the entire breeder development into question, because since the serious accident involving the experimental breeder "Enrico Fermi" (1966), the skeptics increased there.

It is obvious to draw the quintessence from the entire history of nuclear technology to date that future technology projects should be oriented towards needs and market opportunities and not be guided by race psychoses. Nevertheless, the style of breeder politics seemed to be repeated in the field of the new chip "generations": The mere fact of the "chip war" between the USA and Japan was reason enough in both Bonn and East Berlin to push ahead with their own chip development at a cost that could hardly be rationally justified. The actual purpose of this type of "technology policy" was dubious. If the chips themselves represented a major innovation, this did not mean that their production in the founding years had also provided a strong innovative impetus. One expert confirmed the impression of an interviewer for *VDI-Nachrichten in* 1989: "If you talk to the chip experts, you often get the feeling that they are happy if their factory just runs with the available technologies and want to be left alone, just nothing new. "[34]

The questionable nature of nuclear "technology policy" is therefore exemplary. The future prospects of nuclear energy were not only clouded in the seventies, but repeatedly since the early days of nuclear policy. The road to an economically viable nuclear power plant, and even more so to a fast breeder reactor, was much longer than anyone had imagined in the mid-fifties. The oil boom and the coal crisis thwarted the first beginnings of the nuclear commitment; when the first American demonstration nuclear power plant (Shippingport) went into operation in 1957, it turned out that nuclear power was ten times more expensive than coal-fired power. In the sixties, when the first nuclear power plants were commissioned under reasonably economic conditions, the natural gas boom arrived, giving gas a new image of cleanliness and harmlessness and slowing down the advance of electricity into the heating market. At the end of 1966, RWE sent a letter to Research Minister Stoltenberg calling for the "natural gas

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Propaganda" and combating the "natural gas psychosis" became a condition for the entry into nuclear energy.[35]

So even before the controversy of the 1970s, there would have been enough reasons to abandon the development of nuclear energy or to put it on the back burner. But there was no thought of such a change of course; it was generally taken for granted that nuclear energy *had to* come one way or another, no matter how long and thorny the road to it might be. It was traditional ideas of technical progress that led to nuclear energy in the middle of the 20th century with seemingly compelling logic. Conrad Matschoß saw the essence of technical progress since antiquity in the "subjugation of elementary forces", the increase in driving power. The effectiveness of this view of history can be seen in decisive moments of German nuclear policy: Winnacker declared in 1955 in a report on the Geneva Nuclear Conference "that the civilized nations are in a similar situation to the moment of the invention of the steam engine or the electric generator by Werner von Siemens".
"At such moments in the history of technology, positions are taken that will determine our standard of living for decades to come."

Not only the steam engine, but also the advances in chemical synthesis, which transformed many resource problems into energy problems, strengthened the energetic view of history. Theoretically, this idea of progress could also lead to solar energy. However, if electricity is seen as the
"noblest" form of energy and equated progress with the concentration of ever greater power, then nuclear energy was precisely the point that had been missing from the energetic image of progress. Since the 18th century, however, there had been another idea of technical progress: progress as an improvement in the means of communication. However, as long as this was equated with increasing energy consumption, nuclear energy was the result.

The down-to-earth idea in Germany that technical progress was leading in the direction of increasing scientificization and that science was the safest way forward for technology had also been working in favour of nuclear energy since the successes of atomic physics. Finkelnburg, the founder and head of the Siemens reactor department, declared at the VDI's centenary celebrations in 1956 that this move towards the scientificization of technology, which he believed was shortening the time between scientific discovery and practical technical application, would "with absolute certainty" continue to lead to "a tremendous expansion of the field of application and power of technology". He was the most committed champion of the heavy water reactor; he was later said to confuse economics with neutron economics.

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The subsequent fate of nuclear energy showed all too clearly that the development of large-scale technology followed different laws than those of science and that the scientific solution to a problem still meant little for its technical feasibility. In the first half of the 1950s, Finkelnburg and his brother-in-law Hei- senberg already gave the impression that breeder reactor technology was practically available, as the first experimental breeder reactor had been put into operation in the USA in 1951 (it was destroyed by a serious core meltdown accident in 1955). But it was precisely the subsequent history of suffering of the breeder reactor projects that refuted the thesis of the growing affinity between science and technology.[36]

In the early days of German nuclear energy development, theorists had dominated to an astonishing extent. Häfele, the long-standing head of the breeder reactor project, even came from the field of astrophysics; in 1977, however, he admitted that physicists "generally underestimate how difficult it is in engineering terms to get even a single reactor type up and running". The decision in favor of the sodium-cooled breeder reactor, as opposed to alternative breeder concepts, was reached "in agony". "And then in the end it wasn't just any logical argument, but the wealth of technical evidence that supported each other." It depends on where the "greatest level of confidence" exists. "This is not of interest for physical considerations, but for the technical implementation of projects if they are to be commercially viable." A noteworthy statement that can be applied to many areas of technology, especially complicated and confusing ones! Of course, the sodium incubator did not become "commercially viable" either. Only the further course of history will show how evident the "abundance of technical evidence" is!

Experience in power plant construction decided which reactor concepts prevailed: a not unproblematic process due to the novel problems of nuclear technology. In the end, the nuclear research centers were almost irrelevant for the industrially relevant part of nuclear technology, but their large-scale projects provided the nuclear industry with sources of conflict that would not have existed otherwise. Large-scale research and the nuclear industry grew apart; the industrialization of research in no way led to an identity between research and industry. This experience from the history of nuclear energy contains generalizable elements.

Nevertheless, technology policy discourses continue to be dominated by the idea that all scientific and technological progress is a single taut rope that will be blown away by the wind as soon as you cut into it. "If we don't have any nuclear power plants to offer, one day we won't be able to sell any vacuum cleaners either," said Nuclear Minister Balke in 1959. "Based on our knowledge of the history of technology to date," claimed one nuclear apologist after Chernobyl, "it appears to be out of the question.

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skipping individual innovation stages or artificially extending innovation cycles that have already expired. In both cases, there is a risk of social catastrophes, compared to which the Chernobyl accident would have the dimensions of an industrial accident." A few weeks after Chernobyl, a representative of the Bavarian government declared that if Munich, Oskar von Miller's former place of work, had become the "Mecca of microelectronics in Europe", the reprocessing plant near Wackersdorf would be the "Mecca of microelectronics in Europe".
"just another link in this chain". Exaggerated ideas about the synergy between nuclear energy and electronics were circulating. Important calculations for the first German experimental reactor (FR 2) were made with a slide rule; the large computer programs only started up at a time when the reactor concepts had long since been finalized.[37]

The more the concepts of long-term technical development have proliferated in recent decades, the more frequently there has been talk of *"generations"* for technologies: now not only for "new" technologies, but even for trucks. The projection of "generations" has flourished particularly in the case of nuclear technology, which fascinated people not as a fact but as a path into the future. It was assumed that the path of reactor technology would continue over several "generations" up to breeder and fusion power plants; and associated with this was the view that nuclear technology had an immanent tendency towards a closed system, a "fuel cycle". Both visions of the future gave the breeder reactor and reprocessing project a certainty that for a long time could not be shaken by cost explosions or technical difficulties.

This situation meant a handicap for the high-temperature reactor: there was no reprocessing technology for the spherical fuel elements. While in the USA, since the early 1970s, reflections on the possibility of nuclear energy without breeder reactors and reprocessing had been spreading, such thoughts were systematically suppressed in Germany for as long as possible.[38] Even the opponents of nuclear power were initially not interested in such perspectives, because they wanted to disqualify nuclear technology as a whole with the risks of breeder reactors and reprocessing. More recent experience with nuclear technology reminds us that ideas of systems, cycles and generations in technology are metaphorical at best. The fusion reactor, the former "third generation" of nuclear power plants, which was supposed to generate energy according to the principle of the sun, has long since disappeared into an indefinite future anyway, and even many fusion researchers are convinced that it will never exist.

The development of nuclear energy is of exemplary importance not least as the first unsuccessful attempt to mechanize the idea of Europe. Around 1955, when the plan for the *European Atomic Energy Community (Euratom)* took

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nuclear technology seemed the perfect way to give substance to the idea of Europe. "Europe" and the "atom": the two great visions of the time, which promised to bridge many old divides, were united in Euratom. The logic was simple and compelling: huge technical projects demanded a European framework, it was said, and moreover, working together on the technological future seemed to many to be the best way of overcoming the burden of Europe's past. "Technology became a European ideology." Whether technology was put at the service of Europe or Europe at the service of technology remained up in the air. Adenauer, however, knew what he wanted: At the cabinet meeting on October 5, 1956, he declared that via Euratom he wanted to "obtain the possibility of producing nuclear weapons ourselves as quickly as possible", as he no longer trusted the American nuclear umbrella. In public, Bonn's policy sounded completely different. From the 1950s to the present day, "Europe" has been used to justify the compulsion for technical progress and also for large-scale enterprise.[39]

However, the history of the European Atomic Energy Community has been a single tragedy with ever new acts. Instead of promoting European unification, Euratom created a never-ending chain of international disputes that would not have existed without the Atomic Energy Community. The Euratom reactor project ORGEL (heavy water reactor moderated with organic substance) earned scorn and derision from the German nuclear industry. The German nuclear industry harbored a by no means unfounded horror of the bureaucratic centralism of French nuclear policy, with which it was confronted in parts of the Euratom authority. Above all, however, nuclear technology, as Hepp noted, "brought to light the buried needs of national self-expression". No wonder that nuclear power was a particularly poor fit as a basis for a united Europe at the time. It was only in the 1970s, when Germany's ambition to build a breeder reactor was dampened by the steeply rising costs, that it was happy to leave the future of the breeder reactor to a cooperation agreement with France and Italy, the fulfillment of which remained undetermined. "Europe" as a deportation track!

In the period that followed, the prospect of the single European market once again encouraged carefree project-making at European level, as if the Euratom fiasco had never happened. The German EC Commissioner Narjes concluded that the "revolution in communication technologies" meant that European integration had to be intensified. A joint report by European institutes would have us believe that Europe could "consolidate a common identity" in space; Europe must therefore "have its own eyes and ears in space". This is the language of a science fiction world. Once again, the idea of Europe threatened

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to be linked and worn out with technological ambitions far removed from demand.

The most spectacular success of a Franco-German technology project to date is the *Airbus*, which was able to prevail against the competition from Boeing: but only thanks to huge state subsidies, as is the rule with "successes" in the aviation industry. Technology futurists have criticized the fact that the German government was hesitant about the Airbus project for a long time and did not show any great vision; however, Ulrich Kirchner poses the justified question at the end of a detailed analysis of the Airbus story: "Should the German government be blamed for taking so long to decide to promote civil aviation, or was its slowness perhaps quite reasonable? After all, the Federal Republic was able to buy the entry ticket to the Airbus project much more cheaply than France." The Airbus experience shows that skeptical insights from the nuclear power controversy can also be applied to other "future technologies".[40]

Despite "Euratom", the counter-vision of a local miniaturization of the "peaceful atom" also flourished in the early days of nuclear power. In the 1950s, the extremely high concentration of energy in the fissile material often led to the conclusion that a particular advantage of nuclear plants would be that they could be scaled down as required. The "power plant in a box", small reactors to power airplanes and even "baby reactors" for space heating were predicted. Some municipal power plants thought that nuclear power would enable them to regain their autonomy from the big players in the energy industry. In the sixties, such ideas were considered absurd; under the influence of the energy industry, the belief in cost degres- sion with an increase in unit size had become the prevailing doctrine. Whereas 100 MW had been the capacity of a large power plant in the 1920s and 300 MW in the 1950s, after 1960 300 MW was considered sufficient for a demonstration power plant in nuclear energy; in the 1970s the SNR-300 could no longer even be considered a demonstration breeder. Even Mandel, the champion of nuclear energy in the still reluctant RWE, admitted in 1964 that he was "somewhat disappointed",

"how little" even the transition to 300 MW "basically brings", apart from the savings in personnel; in the same year, another spokesperson for the energy industry described it as "irresponsible" to go beyond 300 MW. But a little later, 600 MW and around 1970 1,000 MW were considered the minimum size of an economical nuclear power plant; in 1970, Mandel even predicted reactors of 2,000 MW "and far more" for the future.

"next decades". Schulten, who had initially praised the suitability of the high-temperature reactor (HTR) for small reactors, was planning an HTR of 3,000 MW at the time. However, around 1970, the construction of 1,000 MW

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power plants represented a bold quantum leap that exceeded the scope of previous engineering experience. In the 1970s, the growth in the size of nuclear power plants around the world came to a standstill at a maximum of 1,450 MW; the normal size remained below 1,000 MW.[41]

In the USA, where the trend towards "upscaling" emerged early on, nuclear physicist Alvin Weinberg worried as early as 1952 that focusing exclusively on large-scale facilities could make nuclear technology "perhaps the least flexible of all major technologies". This was exactly the case. Despite the physical novelty of nuclear energy, con- servatism became one of the most remarkable features of large-scale nuclear technology. Because it was believed that there was too little time to gather new experience, the general tendency in the 1960s was to favor those reactor concepts with which there was already a relatively large amount of experience and which were most similar to conventional power plant technology. The high costs involved discouraged experimentation; the development of certain reactor types to market maturity blocked the further development of alternative concepts. There was little real competition between different reactor types, even if even in specialist circles, looking back at the large number of reactor lines that were once pursued, it was later widely believed that the light water reactor had won the competition between reactor types as the optimal solution. Whether the development of nuclear energy can be interpreted as Darwinian evolution with "survival of the fittest", as has sometimes been claimed, is questionable.

The HTR, the only remaining alternative to the light water reactor and - in the future projects - to the sodium breeder, got into trouble due to the drive for size. The safety advantages that this type of reactor had with small dimensions were already doubtful with the 300 MW of the prototype at Hamm-Uentrop; this also worsened the possibility of process heat utilization, which was the special attraction of this reactor line and its particular suitability for German conditions.[42] In general, capacity growth increased the fissile material inventory of the reactors and thus the "residual risk" that existed despite all safety precautions, which under such circumstances was much more than a mere "remainder". At the same time, *economies of scale* reduced the maneuverability of the nuclear industry in the face of the onslaught of criticism in the 1970s. In the eighties, increasingly after Chernobyl, the slogan of *downscaling* came into circulation. Old plans for a small HTR were revived in the hope of making up for the economic disadvantages of downscaling through export opportunities, better acceptance, approval independent of location and series production. So far, everything has gone to waste: such a turnaround contradicted the now century-old growth path of the German energy industry and power plant technology.

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Nevertheless, the controversy surrounding nuclear energy brought about an epochal breakthrough in the public debate on areas of risk to which political regulation and social reaction had previously failed. The extent of the nuclear risk forced the consideration of hypothetical and highly improbable incidents for which no experience was yet available, such as disasters that could be triggered by unforeseen external influences or by a coincidental combination of several circumstances. Precautions against such risks did not correspond to the previous tradition of technology; here, nuclear energy was assigned a "pathfinder role" (Häfele).[43] The critics did not need to do anything other than insist that the officially declared high safety criteria were taken seriously. In the course of the 1970s, the reactor safety authorities postulated, at least in principle, that hypothetical risks also had to be included in the safety assessment. With other "new technologies" such as computer and genetic engineering, on the other hand, this "safety philosophy" has hardly been accepted in principle, not to mention the latest nanotechnology. The hypothetical risks, which were still somewhat definable in the case of nuclear technology, are becoming increasingly unclear. How politicians should deal with this is - no wonder - completely open.

But even in nuclear technology, it was one thing to admit the novelty of the risk in principle and another to draw practical consequences from it. In the practical behavior of many of those involved, the old attitude of regarding safety precautions as a nuisance and something to be warded off if possible, and risk-taking as a sign of masculine energy, dominated until the 1970s. As late as 1983, even Federal Foreign Minister Genscher made the "first demand" for technology policy to "return to the virtue of courage". Engineers were often more cautious than physicists, but it was difficult for them to follow the new imperative and take precautions against incidents that had never happened before, because in the past, technical safety had usually been increased by trial and error and by analyzing accidents that had occurred.

As far as can be seen, a safety approach based closely on conventional power plant technology prevailed in nuclear engineering practice, as is hardly to be avoided. The focus was entirely on the control, shutdown and emergency cooling devices. Even material testing, a core area of technical safety familiar from the railroads, was a tricky problem under the conditions of extremely high levels of radioactive radiation and was tackled only hesitantly. Only gradually did it become apparent that German heavy industry was prepared to meet the material requirements of the reactor industry.

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When higher quality standards for reactor steel were introduced in the 1970s after initial worrying experiences, pressure vessels had to be temporarily sourced from Japan. The postulate of securing nuclear power plants against external influences ("EVA") could only be implemented in technical precautions to a very limited extent.[44] In addition, historical experience gave little reason to hope that safety could be guaranteed in advance with a partially new type of technology; it is not certain whether computer simulation has created a completely new situation here. In the end, the development of nuclear energy could not help but progress by trial and error, but the field of experimentation that can be affected by the consequences of an error is worldwide. Learning through experience is more difficult here than ever before in the history of technology, because it is precisely in the case of major incidents that it is initially very difficult to gain an overview of what has happened and its consequences.

The suppression and rediscovery of the "human risk factor" took place dramatically in the course of the reactor safety debate. Based on the experience of the history of technology, the "human factor" should have been given special attention when considering safety, as human error has always ranked first among the causes of accidents in technology. If one assumes that man is an imperfect being, one comes to the conclusion that incidents caused by human error point to errors in technology: a seminal idea for the entire consideration of technical safety, which led to the postulate of "error-friendly" technology. For a long time, however, people in German nuclear power plants believed in the necessity of technology without humans due to human fallibility. The idea of maximum automation was associated with reactor technology at an early stage; the automation and elimination of humans was even sometimes presented as a specifically German safety philosophy compared to that of American reactor builders, who relied "very heavily on humans",[45] although Germany traditionally lagged behind the USA in the field of automation. Münzinger warned early on not to be blinded by the highly complicated automatic safety precautions of American nuclear power plants, as "experience has shown that especially those automatic devices that only rarely come into operation easily fail when needed."

So we had to rely on the people in the reactor control room again. However, if we thought the question of the type of people and society required by nuclear technology through to its logical conclusion, we ended up with absurdities: Alvin Weinberg postulated a "nuclear priesthood" with

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political and moral stability corresponding to the decades of the half-life of plutonium. Anyone with even a hint of historical education understood the absurdity of this postulate. There was a reason why reactor safety experts were generally hesitant and reluctant to address the "human risk factor"; in the case of nuclear technology, the subject was tricky, and nowhere did expert competence reach its limits more visibly than here. It was thanks to the public controversy that this topic ultimately became irrefutable; it has remained an open question ever since.[46]

The main targets of the protest were the breeder reactor and *reprocessing (WA)*. The history of the West German WA plans offers a prime example of misleading semantics and system illusions. In plain language and in accordance with its military origins, WA meant plutonium production. Under the name "WA", however, it was presented as a necessary component of civilian nuclear technology: as "closing the fuel cycle" through plutonium recycling. Around 1975, in view of the gathering protest movement, WA was additionally legitimized as a necessary prerequisite for the final disposal of "nuclear waste". It is ironic that it was precisely this new and specifically German classification of WA under the heading of "disposal" that created the compulsion for the rapid construction of a large-scale WA facility; the modest plutonium recycling program alone would not have given rise to the massive Gorleben project. It was precisely in this situation that the high risks of WA were revealed, which until then had hardly been noticed by the public. In the 1980s, all ecological interest in the WA disappeared when it became clear that the earth's uranium reserves would not last for decades, as previously assumed, but for centuries, even without the WA; the WA only remained of interest to the energy industry as an object of depreciation. In the 1980s, the great debate that the dilemma of nuclear waste disposal provoked expanded into a general discussion about the waste disposal dilemma in industrial civilization.

In principle, the nuclear risks could have been recognized, even if not in every detail, at a time when civilian nuclear technology had not yet progressed beyond small test facilities. The history of nuclear energy indicates that a forward-looking technology assessment is perfectly possible even for new technologies and that the real problem lies in translating the findings into practical conclusions. This is especially true when dangers do not manifest themselves acutely and perceptibly, as in the case of steam boiler explosions, the classic subject of technical safety research. In the case of nuclear energy, the risk to be borne by the private sector was narrowly limited at an early stage and the

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The enormous remainder was imposed on the general public.[47] But it was precisely this that ultimately encouraged public discussion and the politicization of the problem. Whoever is to bear the risk has a right to full information and a free decision.

The genesis of nuclear technology can be traced back to state measures all over the world, including in the Federal Republic of Germany, where the industrial use of nuclear energy was made a matter for the private sector more than elsewhere. Nevertheless, state records generally lack any awareness of the state's freedom of decision with regard to nuclear energy; most of the responsible ministerial officials and parliamentarians seem to have seen themselves primarily as enforcers of constraints and as acceptance seekers. The history of nuclear energy shows that active state involvement in certain technologies in no way strengthens the political control of the technology, but on the contrary entangles the state in partial interests and makes politicians dependent on expert cartels.

For a long time, the argument was popular - especially on the left - that the ever-increasing cost of technological progress required increasing state involvement as a matter of law. But this argument is contestable in all its components. In Japan, which is usually held up as a role model today, expenditure on research and development amounted to 1.6 percent of industrial turnover in 1977 (Germany: 3.3 percent); the public share of this was 28 percent (Germany: 46.7 percent). In the case of Japanese electrical engineering and electronics, of all industries, the government share of research and development expenditure in 1975 amounted to just two percent![48] Even if nuclear energy were considered indispensable, this would not mean that government subsidies were necessary, as the light water reactors were brought onto the market by German industry in contradiction to the policy of the government and the nuclear research centers. Without state pressure and massive use of public funds, however, the breeder reactor and reprocessing project would in all probability have remained stuck at an early stage and nuclear energy would have been spared the most sustainable sources of conflict. The entire experience of history indicates that state bureaucracies are much better equipped to delay and control than to successfully develop new technologies. For reasons of both principle and practice, environmental policy corresponds far more to the function of the state than technology policy. Experience shows, however, that public pressure is necessary for the state to fulfill this function.

The fact that public sentiment plays a role in the launch of a new technology is nothing new in the history of technology.

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railroads, the world's fairs, early electric magic and motor racing, new technologies that were bound to gain public support and inspire the imagination used to be accompanied by a wave of journalistic euphoria. Although the initial exuberance was usually followed by disillusionment, these overtures are repeated with wearying regularity right up to the present day, and it is still part of the style of popular literature on new technologies to mix facts and speculation, often indistinguishably. All this seems to confirm the skeptical image of the public in the age of mass media, according to which "public" has become "published opinion" and a reflex of manipulation. Opinion polls show that the "atomic age" euphoria of the fifties was predominantly a journalistic phenomenon and was not shared by the vast majority of the population. The protest movement of the seventies had to defend itself against the media until around 1974; it was only through spectacular actions such as the occupation of the Wyhl construction site that it and the risks of nuclear technology became newsworthy and sensational.[49]

In the period that followed, however, the general mood changed. The public became a critical force to an unexpected degree. It did not remain extra-parliamentary, but provided the impetus for technology policy to become the subject of intensive parliamentary debate for the first time in history. New topics that had been neglected in the expert discussion came into focus: large parts of the nuclear "residual risk", the risks resulting from human error or malicious acts and finally, under the influence of the peace movement, the proliferation problem. What was unthinkable in expert committees could be articulated in public: that it is possible to abandon nuclear energy.

The protest movement had an unusual impact, not least because the economic viability of nuclear technology and the demand for nuclear power was worse than many had previously believed, and because there were conflicting and competing interests in business and science regarding nuclear energy or at least the nuclear projects of the future; the nuclear conflict gave these interests the opportunity to form. Coal, which until then had been won over as a partner of nuclear energy by the supposed prospect of "coal refinement" through HTR process heat, gradually distanced itself. In the 1980s, the Federal Republic fell apart into "coal countries" and "nuclear energy countries". Other "new technologies" such as information technology and genetic engineering, which are based on other images of progress, contributed to the dismantling of the "energy" image of progress.

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The debate on genetic engineering, which developed in the USA as early as the 1970s in the vicinity of the nuclear conflict, has also shown similarities with this precursor controversy in Germany since around 1984: The paradigmatic significance of the debate about nuclear energy has become increasingly apparent in the technology debate - sometimes with the danger of construing other risks too much in analogy to those of nuclear technology. After all, genetic engineering is also a field of risk with eventualities that threaten humanity, although the potential dangers can only be determined hypothetically for the most part. The relatively cautious approach to genetic engineering in Germany and other EU countries to date confirms the "pathfinder role" of the nuclear power controversy.[50]

5. Humanization of technology through technical progress or: human and environmental friendliness as an accidental by-product of technical change?

If we can speak of a "revolu- tion" in the history of technology in recent decades, it is not only in the technology as such, but at least as much in the change in lifestyle marked by technical props and in the consequential problems caused by production and consumption. Here, too, the period around 1957 marked a first turning point, both in the dimensions of the problem and in how it was perceived. In 1957, the VDI Commission on Air Pollution Control was founded by upgrading a previous committee: The development of technical rules to limit emissions at the level of the VDI and industrial self-administration took place with greater emphasis, not least in order to pre-empt government regulations. The era of coal dominance, in which industrial cities had become accustomed to a fatalistic attitude towards smoking chimneys, had been brought to an end by the oil boom and the "nuclear age" expectation. The Ruhr district had to watch as it became attractive to new industries. At the end of the 1950s, the "brown smoke" over the smelting works triggered a violent wave of protest; in 1961, the "blue sky over the Ruhr" was one of the SPD's election campaign slogans. In 1960, a research institute for air pollution control was set up on a private basis; after crossfire from industry, it was taken over by the state of North Rhine-Westphalia in 1963. However, the "TA Luft" (Technical Instructions on Air Quality Control) of 1974 were still largely based on the existing "state of the art" and on technical standards that had been developed in the pre-state area by the VDI and the German Association of Engineers.

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industry had been defined. The "ecological revolution" around 1970, when the Federal Ministry of the Interior invented "environmental policy" based on the American model, initially consisted mainly of a publicity-effective networking of long-existing sectors such as air pollution control, water protection, occupational safety and hygiene.

The Federal Institute (since 1972 Federal Institute) for Occupational Safety and Health was founded in 1957. When full employment was reached and labor became precious, there was reason to reactivate the long-neglected occupational safety. In 1961, the number of accidents at work reached an alarming high of 2.8 million; in 1962, Balke appealed to industry to see occupational safety as a corporate responsibility. But there was no effective change in behavior; at the beginning of the 1970s, German industry still had the highest accident rate in Western Europe after Italy. Towards the end of the seventies, the number of premature invalids in industry was still "rising dramatically". The growing pace and fear of unemployment undermined occupational safety measures.[51]

The Federal Ministry of Health was founded in 1961. It was at this time that the *Contergan (thalidomide) affair* began to hit the headlines: the incidence of deformities in newborns whose mothers had taken the thalidomide-containing sleeping pill during pregnancy, which the chemical company Chemie Grünenthal had launched on October 1, 1957. It was the first major catastrophe alarm that drew attention to the risk dimensions of the glut of medication; however, in the 1960s, when the anti-baby pill became a byword for progress, especially for the left, it met with surprisingly little response - nothing like a protest movement. In retrospect, it is hard to believe that there was no public outcry of indignation. The wall of silence erected by the pharmaceutical-medical complex had mafia-like characteristics. The proceedings against the company, which involved a huge paper war on both sides, were dropped in December 1970 without a verdict. The lack of product liability in the pharmaceutical industry in Germany, in contrast to the USA, which benefited from a "culture of almost unlimited trust" (Willibald Steinmetz) in Germany thanks to its great past, became a scandal. A Swedish study found that the Federal Republic, although "the country most severely affected by the thalidomide disaster", had "not learned from this experience". It was only with the growing popularity of natural healing methods that the public mood changed in the 1980s. However, efforts to effectively and systematically test the effects of new medicines were just as unsuccessful as similar approaches at the end of the 19th century during the founding period of the Imperial Health Office.[52]

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In the late 1950s, the realization began to dawn that water supply and disposal were heading for a critical situation. After the regulation of water management had been repeatedly delayed since the turn of the century, a draft framework law, the Water Resources Act, was passed in 1957. Also in 1957, the federal competences for water management were transferred to the Ministry of Atomic Energy, although (or because) the most effective opposition to nuclear plants came from water management circles at the time. Efforts to fill in the content of the framework law met with unabated fierce resistance from industry; even in the seventies, the interested parties remained firm and the state governments timid. At the same time, visually impressive successes in reducing water pollution were still relatively easy to achieve by technical means. The new trend is that while rivers are becoming cleaner, the more dangerous and irreversible pollution of groundwater is increasing. In the past, as today, the pollution of flowing waters was the area of environmental damage where government regulations were most effective; therefore, the "management" of environmental problems often consisted of shifting them to areas (groundwater, soil, air) that were more difficult to deal with.

The problems themselves grew considerably more than the awareness of the problem, if only due to car traffic, which was given more free rein than ever since 1960 with the earmarking of vehicle tax. The policy of tall chimneys reached its culmination after 1960 with heights of 150 to 200 meters. The extent to which this period represents a caesura in environmental history, which remained hidden to most contemporaries, was shown by studies on forest damage in the 1980s: around 1960, the annual rings of damaged trees narrowed in many cases. Since then, the nitrogen oxide emissions curve has continued to rise. Industrial emissions, which had always damaged the health of workers, alarmed the public when their consequences became apparent in the forests.[53]

Motives and group mentalities that had previously been scattered and separate in German history gradually came together to form a movement that found its term in 1970, following the American model of the "environment": Nature conservation and natural healing movement, life reform and love of craftsmanship, socialism and nostalgia, women's and peace movement, communal resistance to centralized energy supply and residents' initiatives against noise pollution from traffic. A conflict arose between the social and technical ideas of progress; the long-standing latent tension became an open rupture. Prior to 1970, the environmental movement had already been in a long latency phase; the popularity and popularity that the German environmental movement had enjoyed since the 1970s

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The fact that the environmental issues were characterized by a flood of discussions and publications, ordinances and political statements on the environment, however, distracted from the fact that the effects were disproportionate to the words. But the flood of discussions and publications, regulations and political statements on the environment distracted from the fact that the effects were disproportionate to the words and in many areas did not keep up with the pace of increasing environmental pollution.

A good part of the dilemma certainly lies in the difficulty of the matter itself; another part is due to industrial interests and consumer inertia. However, one must also ask to what extent the solution strategies pursued were appropriate to the problem and whether - as at the turn of the century - pseudo-solutions did not prematurely convey a sense of satisfaction. There was still the dogma, albeit with some reservations, that technological progress would solve the consequential problems of technology by itself in the long term if it was only pursued consistently and intelligently. In 1988, a VDI declaration entitled "Rationalization today" contained the thesis that rationalization included environmental protection by minimizing "the consumption of energy and material resources" and also encompassing "sensible disposal concepts". The advance of VDU workstations created a new situation in occupational health and safety: traditional physical stresses receded and were replaced by new types of mental and nervous stresses to which occupational health and safety was not - and still is not - really adapted.

Even among those who criticize the inhumanity and environmental harmfulness of the mainstream of technological advances to date, there is a tendency to understand the "alternative" as essentially technical as well, sometimes using the concept of the "alternative" that dates back to the days of the electric vision.

"neotechnology" of Lewis Mumford: the humane and environmentally friendly new technology that heals the wounds of the dark coal age.[54] The new concept of the "ecosystem" as a concept of a "hard", quantifying computer ecology also leads to thinking of ecological policy as the restoration of a system or cycle; in this respect, it can contain a technicist tendency in a figurative sense. The mechanization of environmental protection is all the more tempting because in this way, at least in idea, the harsh distributional conflicts that arise from a domestic approach to resources remain concealed. After the turn of the millennium, however, the general public became aware of what we could have known all along: that although biofuel may be a "gentle way" compared to nuclear power from a purely technical point of view, it is by no means so from a socio-political point of view, as the production of energy sources in this way competes with the production of foodstuffs.

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oil crisis and nuclear power together with a concept of the ecosystem that "all biological interactions reduced to energy terms", *energy policy became the* focus of the environmental debate. This focus favored technical solution strategies. The most impressive example of the fact that technical progress can coincide with the conservation of resources was in the 1970s, just as it was in the early 1990s.

The 20th century saw the improved use of energy. While it was still believed at the beginning of the 1970s that German industry had almost fulfilled the "energy imperative" after all the rationalization pushes, it soon became a surprising revelation after the oil price jump in autumn 1973 that there was still enormous, constantly expanding scope for energy savings. This cast a new, sharper light on the history of industrial technology and at the same time on current technical opportunities. The opportunities to save energy took both the energy forecasts and expansion plans of the supporters of nuclear power and the solar visions of the opposing side by surprise. "Saving is the energy source of the future" became an American-style slogan at the end of the 1970s, which created a certain consensus after the heated phase of the nuclear conflict (1975-79).

On the other hand, the long-standing demand that solar technology should be given the same development opportunities as nuclear technology has so far only been partially fulfilled. To date, there has been no major public debate as to whether solar energy in Germany should be regarded as the epitome of an adapted technology or one that mocks the climatic conditions. For decades, the energy policy situation in Germany has been characterized by a stalemate between the established powers of the energy industry and the protagonists of renewable energies. Incidentally, the fixation on high-tech often overlooks the fact that the most effective energy-saving technologies are largely of a trivial nature: Thermal insulation in the home and replacing the car with the bicycle.[55]

The history of *limit values* shows dramatic progress. In 1873, over 30,000 milligrams of sulphur dioxide per cubic meter of air were considered tolerable for factory workers for a long time; today, the WHO recommends an average value of 0.05 milligrams.[56] As recently as the 1930s, dust emissions from cement plants exceeded 10,000 milligrams per cubic meter; today, only 50 milligrams are permitted in Germany. The strategy of limit values began in the late 19th century as a predominantly symbolic policy: in many cases, it was initially impossible to monitor compliance with the set limit values. However, as measurement methods improved, it became a policy that was effective in real terms. Of course, progress also has its downside: the processes reveal the extent to w h i c h what was

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is a function of what is technically possible and economically acceptable. Even Nuclear Minister Balke repeatedly pointed out the scientifically uncertain nature of the "tolerance limits" and characterized them as "reassurance limits".[57]

The utilization of residual materials, *recycling*, which was rediscovered as a guiding principle in the eco-era, has in part coincided with the main lines of technical progress in chemistry for over a hundred years. Henry Ford also proclaimed the principle of the useful utilization of waste. Starting in the USA in the 1970s, recycling became a growth industry and in some cases a highly specialized technical sector in its own right. In the case of highly toxic substances such as plutonium and cadmium, however, recycling increases the dilemma: In contrast to direct disposal, their permanent and ubiquitous spread is promoted in this way. Plutonium only becomes available in its hazardous pure form through WEEE; the spread of cadmium is also increased by recycling. According to one calculation, filtering out a single kilogram of cadmium, the market price of which is three marks, costs around 60,000 marks in a sewage treatment plant, whereas it can be retained at the point of origin using comparatively simple processes. As the nuclear "fuel cycle" has already shown, large-scale recycling is based on dangerous system and cycle illusions.[58] In the 1990s, the *"Dual System Germany*" - waste separation with maximum recycling - became the flagship of German environmental policy. However, the extent to which this *"end-of-the-pipe"* strategy is actually forward-looking or rather a dead end that distracts from forward-looking waste prevention has become the subject of fierce controversy.

Waste disposal - the term became common property through nuclear technology - advanced to large-scale technology in the 20th century and has accordingly already produced its own expert cartels and moments of inertia. By combining mechanical, chemical and biological plants, sewage treatment plants became industrial-like complexes and a reflection of the spectrum of natural sciences. Waste incineration plants had been around in England since 1876; Hamburg was the first continental European city to build an incineration plant in 1895/96 after the cholera epidemic, and at the turn of the century, incineration was generally regarded as the waste disposal method of the future in Germany. But the poor war and post-war periods, when the waste contained too little combustible material, thwarted these plans. In the sixties and seventies, waste incineration in the Federal Republic of Germany was an innovation that only became established after some development work and was seen as a major solution to the waste disposal problem; the new waste incineration plants could be compared architecturally with modern universities. In 1984, however, the mood changed,

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when reports of dioxin damage from Hamburg incineration plants went through the media; the "end of the era of waste incineration" had barely begun when it was prophesied: prematurely, as we know today. In the 1980s, the increasingly monumental disposal technology symbolized the dilemma more than the technical solvability of disposal. The prospect of "retrofitting" the sewage treatment plants in the Federal Republic of Germany in 1989 was estimated at a total of 100 billion German marks; this threatened to put disposal technology beyond the financial reach of local authorities. At times, *genetic engineering* was hailed as the future savior, in the expectation that newly combined microorganisms would decompose the extremely resistant waste and pollutants and render them harmless; but such hopes were rejected in 1986 even by a spokesman for Hoechst AG, which was the first major German company to become involved in genetic engineering.[59] For its part, genetic engineering poses disposal problems that are even more unsolvable in principle than those of nuclear technology, because released microorganisms can no longer be retrieved and have no half-life, but can multiply and adapt to the environment. Even if most of the microorganisms cultivated to date are not able to survive outside the laboratory in most cases, the ambition of researchers is to make them more resistant. In this respect, there is a discrepancy between "progress" within the field and safety for the outside world.

Securing peace through technology: Even before 1914 and in the interwar period, it was prophesied - unfortunately all too early - that technology was "about to destroy war", this dream of a technical guarantee of peace through the "balance of deterrence" seemed to be coming true. At a certain stage of nuclear weapons technology, when it was used more for deterrence than for military operations, this may have been true. However, since the "rearmament" debate at the end of the 1970s, the public has become aware that the ambition of missile engineers was to make nuclear warfare feasible and once again create the illusion of superiority secured by a technical advantage. In the global debate on the Non-Proliferation Treaty (NPT), which began around 1966 and was fiercely opposed by the German right for many years, the Federal Republic's particularly constructive contribution was the mechanization and thus political defusing of the control problem, the "instrumented fissile material flow control". The general applause that this idea met with distracted from the fact that its effective feasibility had not been clarified in any way. The erroneous idea that nuclear plants are in principle large automatic machines led to the false assumption that the control of the fissile material flow could also be automated. In reality, the rule still applies today that effective control

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The end of the East-West conflict meant that the risk of nuclear proliferation and the risk of war inherent in new technological developments in general disappeared from public debate for a while, but the problem has by no means been definitively resolved.

Since the 1950s, *the "humanization" of the world of work* has been the new term for the old-fashioned "joy of work", along the lines of American "human relations". Here, too, the view is popular that computerization has an inherent tendency to put people back at the center of the production process. At first glance, computer workstations fulfill the old dream of "hygiene" in industrial work to an unprecedented degree. As workers no longer come into direct contact with the machinery and the material being processed, the most obvious source of accidents in the workplace is eliminated. On the other hand, the control and nervous strain of the work can be increased. The hope that technical innovations will automatically lead to
The "end of the division of labor" has no historical basis: the division of labor is of pre-industrial origin, and there is no reason to assume that it will be abolished by new technology. Since technological progress as such is aimed at maximum process control, it often - if not always and necessarily - also reinforces the domination of people, unless countervailing forces come into action. Mass unemployment, which has been increasing for decades, favours a ruthless style of rationalization despite all the euphemisms. The much-vaunted flexibility of the new technology also offers the possibility of using it to strengthen existing production structures. Similar to the hopes of the 1920s that technological progress would bring about an enrichment and higher qualification of work, there is reason to suspect that optimistic forecasts result from an - explicit or tacit - restriction of the perspective to certain skilled worker elites.

It cannot even be said that tools are becoming more anthropomorphic as a result of technical progress. The ergonomically perfect tool - as one expert succinctly remarked - cannot exist "for one simple reason"; "because it is mass-produced". In general, there is still a tension between ergonomics and economic calculation, and a direct contradiction between ergonomics and mass production. Computers have created an outwardly completely new world of work, but well-known problems of - in today's jargon - ergonomics have been overcome.
The "human-machine interface" returns in a new guise on the user interface of computers. A history of computer technology concludes in 2001 with the sobering assessment: "In view of the enormous quantitative

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Despite the progress that interaction with computers has made in the last 15 years - higher working speeds, larger storage capacities and better resolutions of output devices - qualitative progress in the interface has by and large failed to materialize. "[62]

While a number of recent trends in technological change are partly positive or at least ambivalent with regard to the environment and humanization, other major trends are all the more cause for concern. The problematic "hazardous waste" is growing rapidly and, on top of that
"increasingly toxic". The former State Secretary in the Federal Ministry of the Interior, Günter Hartkopf, had to register an "exponential increase in substances for which carcinogenic or cancer-promoting effects have been observed" in the world of work, despite all the pride he took in the protective measures implemented under his direction. Even the number of officially recognized carcinogenic substances increased twenty-fold from the 1960s to the 1980s; according to the head of BASF's toxicology department, the criteria for classifying suspected substances had become more stringent by 1979.
"completely open", where the focus is not on acute but on chronic effects. Particularly with regard to chemicals, German environmental policy needed external impetus; this is where the traditional power of the chemical lobby made itself felt.[63]

Chlorine became "a key product and indicator of the state of the chemical industry", particularly through the production of plastics, but at the same time it became the key substance for a whole series of the worst sources of danger in modern chemistry. The beginnings of this development date back to the early 20th century, but in the 1950s and 1960s the problem reached historically unprecedented proportions. From 1940 to 1970, the annual chlorine consumption at Chemische Werke Hüls rose from 10,000 to
250,000 tons and to 450,000 tons by 1977. The growing use of plastics generally exacerbates the disposal crisis, especially when it comes to stable and highly resistant "new materials". In materials development, there is often a direct contradiction between what is regarded as "technical progress" and ecologically safe disposal. At the "New Materials" special show, which has been part of the Hanover trade fair since 1986, "the question of recycling options compared to metal is usually met with an awkward silence". "Composite materials" with different material layers are regarded as the materials of the future; but
"the more complex the new materials are, the more difficult they are to dispose of". Today, new materials are routinely combined according to computer calculations. As early as 1988, an employee of the Federal Institute for Occupational Safety and Health reported that there were already six million "mixtures that no-one could keep track of".[64]

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There has been a particularly glaring contradiction between ecology and mechanization in *agriculture* in recent decades. From a historical perspective, this turnaround is all the more fatal as, until the early 20th century, agricultural interests partly represented a counterbalance to industrial environmental damage. The pollution of groundwater by agricultural nitrates is now an even more acute problem than industrial water pollution. The use of the pesticide DDT, whose ecologically devastating effects helped trigger the environmental alarm in the 1960s in the USA, was banned in Germany in 1971; however, it is still permissible to export insecticides banned in this country - well into the eco-era, Germany was still the "largest exporter of pesticides in the world".[65]

Although sulphur emissions from power plants are being reduced, traffic-related nitrogen oxide emissions are still on the rise. According to the President of the Federal Environment Agency, the Germans are "the biggest polluters in Europe" in this respect. However, this compliment from the competition should be taken with a pinch of salt: as soon as a speed limit was imposed in the USA and other export markets, the ongoing progress in engine refinement was no longer worth much. In 1976, Dahrendorf found it "almost incomprehensible and at the same time telling that it is not even possible in the Federal Republic to even discuss the speed limits on freeways that almost all neighbors have introduced".[66] In the period that followed, this discussion took place, but without any practical effect. In 1988, Federal Transport Minister Warnke even declared in all seriousness that a speed limit of 100 km/h was "against the nature of the motorist"; in 1989, the German car industry advertised with a Fiat compliment: "As long as there is no speed limit on German freeways, your industry has a clear competitive advantage."

Even the red-green federal government did not dare to introduce a general speed limit. Only traffic-calmed zones have increased significantly in recent decades: One is reminded of the "solution" to urban environmental problems through zoning a hundred years ago. This may have contributed to the fact that the topic of "speed limits" has been more or less ignored for some time, even by the environmental movement. Yet there is much to suggest that German car manufacturers are maneuvering themselves into a dead end with the high-speed profile. In 1985, the risk of being killed in a car accident in Germany was "about twice as high as in Japan or Great Britain". Crumple zones only increase the chances of survival for car occupants; if they encourage speeding, they increase the risk for potential victims outside the car. From the point of view of the possibilities of modern technical transportation systems, the car is not a very safe vehicle.

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satisfying means of transportation. But the power of the car lobby meets the powerful trend towards the most individual motorization possible.

In the "ecological age" of all times, air traffic has increased dramatically and the airplane has become a normal means of transport. The tax-free status of kerosene gave air travel a head start, which grew ever wider with increased fuel taxes. The environmental movement never showed much desire to tackle this issue either, as many members of the "eco-scene" harbor at least as strong exotic longings as the rest of the population. Safety in German air traffic has recently been called into question by the strong international growth dynamic and the European liberalization of air traffic; from the perspective of the German pilots' organization Cockpit, there is a threat of "airspace overcrowding" and a "deterioration in safety standards" in the narrow confines of the Federal Republic.[67]

German transport policy in the 1980s also adopted the style of large-scale projects for the railroads, which had attracted little attention in terms of technology for over a century: with high-speed lines requiring new routes - only eight kilometers of the 111 kilometers between Kassel and Fulda run at ground level - and with the "Transrapid" magnetic levitation train, which required completely new route technology. The two projects competed with each other. Instead of using the railroad to reduce road traffic, the strategy was to colossally expand the niche of long-distance passenger transport left by the car, although the small size of Germany meant that this expansion quickly reached its limits and the railroad made by far the highest profits in regional transport. A "speed gap" between rail and air was constructed for the Transrapid, and it was also propagated as a replacement for the airplane in view of the threat of overcrowding in German airspace.

The magnetic levitation *train*, which avoids the friction losses of rail transportation, thereby saving energy and reducing material wear, was once considered comparatively environmentally friendly, even gentle. In Ernst Callenbach's "Öko- topia" (1975), the inhabitants of the fictitious eco-state travel in maglev trains in complete comfort: There "is no wheel chatter, no engine whine and no vibrations", even though the train races along at an average speed of 360 km/h. For ambitious technologists, this technology also had the appeal of "basic innovation", science-based high-tech, combined with elegance: it was a charismatic technology that made its fans "sparkle in their eyes". The German Trans- rapid project, whose origins date back to the early 1970s, the beginnings of the eco-era, became the German way into the railroad future for its champions. In 1989, the Federal Ministry of Research, after

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The Transrapid will decide whether we are still a modern industrialized country or not." Within the ministry, Wolfgang Finke, once a dis- sident in the nuclear community, was the strong man behind the Transrapid project.

The controversy over the Transrapid is one of the most exciting debates in the history of German technology, as the fronts were not fixed from the outset, but ran right across the parties, and this technology presented itself ambivalently from both an energy and an environmental perspective. As is so often the case in the history of technology, the devil was in the detail as soon as the project became reality. It turned out that the energy-saving effect only came into play over long distances at top speed, but that the supposedly "whispering arrow" caused the noise of a low-flying plane at top speed. What's more, the previously held assumption that the wheel-rail system did not allow for any speed reduction was no longer valid.

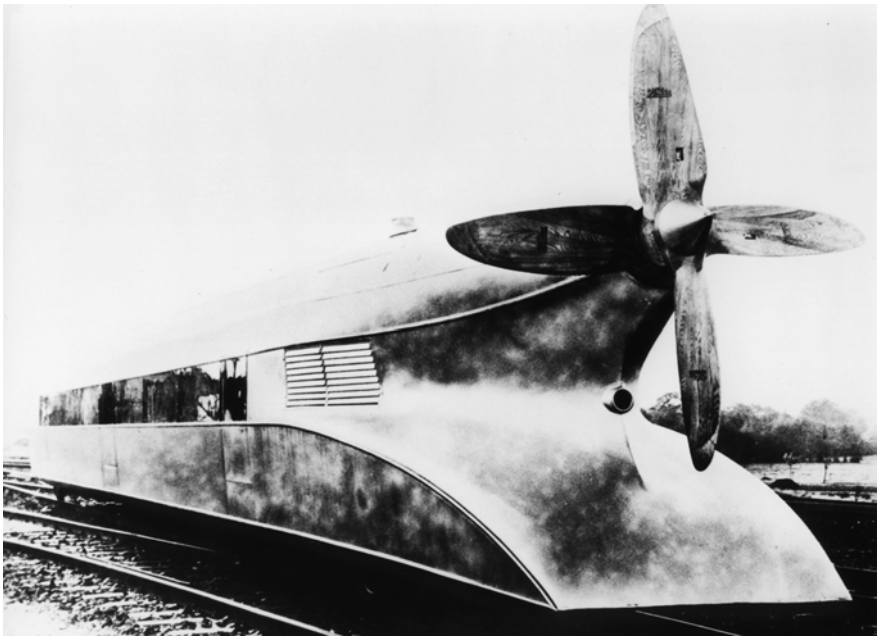

Figure 40: A forerunner of the maglev train and an early attempt to combine rail and flight technology: the propeller-driven "Schienenzeppelin" developed by engineer Franz Kruckenberg in 1928 - at a time when the Zeppelin was still inspiring dreams of conquering the world with German technology! Kruckenberg founded a "Flugbahngesellschaft" in Heidelberg and achieved a record speed of 230 kilometers per hour on the Berlin-Hamburg route on June 21, 1931. Like the Transrapid later on, the rail zeppelin was a brilliant idea in purely technical terms; however, as Lutz Engelskirchen summarizes, it was too far removed from all current railroad technology to have any chance of being implemented.

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increase beyond 250 km/h turned out to be wrong. Actually, this could have been known since the 1960s from Japanese high-speed trains; but at that time these were still "too far away and could be ignored in the German technical sciences" (Hans-Liudger Dienel). In retrospect, the failure of the Transrapid has a paradigmatic character: it illustrates that new space-filling technical systems in areas that have long been occupied by other large-scale systems do not stand a chance so easily, despite their theoretical advantages - and that a "basic innovation" as such does not guarantee success in the least. The narrower the German area becomes, the more decisive the ability to connect to existing systems will be for the success of new transportation systems.

History can give us an idea of what a real traffic turnaround would look like: It would be there if private motorized transport were replaced by public transport and bicycles in large cities, if a large network of intersection-free bicycle lanes were set up alongside the railways and freeways and if people could routinely make a career out of environmental commitment in politics and business. So far, such ideas have been almost impossible to imagine and express without ridicule. In parts of industry, the environmental movement has led to sharp defensive reactions and the creation of a counter-front; the most visible example is the "bunker mentality" developed by the nuclear industry in the great controversy. It has happened that even spokespersons for industries that benefit from environmental protection have joined in the knee-jerk defensive reaction against environmental regulations.

In Germany, more than in many other countries in the world, there is a long tradition of impressive partial and pseudo-solutions in dealing with the harmful consequences of technology: through external cleanliness, order and precision, through optimization of energy efficiency, chemical waste recycling and nature conservation in limited reserves. The tradition of industrial self-administration, stubbornly defended by business and technology, and the defense against legal regulations and state control could also have a blocking effect, supported by the idea that the wounds inflicted by technology can only be healed by new technology. This idea is all the more seductive as there is in fact no lack of impressive examples of the convergence of technological and ecological progress.

Overall, however, it is difficult to doubt the fundamental contradiction between technology development geared towards business interests and environmental concerns. It follows that effective solution strategies, if they exist at all, require strong legal and administrative backing.[68] If, on the other hand, industry and technology are the main

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As the world's political leaders emphasize the personal responsibility of practitioners and large parts of the alternative movement expect salvation to come primarily from concern and a new awareness, the anti-bureaucratism of industry can meet with the "alternative" horror of the state, let alone the nation state, as a practical consequence. As in the early 20th century, an era of pseudo-solutions could be followed by an era of fatalism.

However, emphasizing the need for comprehensive political regulation poses a dilemma: As past experience has shown, environmental policy easily becomes a merely "symbolic" ac- tion that may have a long track record of policy statements, laws and regulations, but tends to obscure the effective failure to address the issue. In the case of new technologies, the administration prefers to pass the buck back to the technicians by linking approvability to a "state of the art"; in doing so, it promotes the emergence of expert cartels that make legally reliable statements about this "state of the art". However, environmental policy has little chance if it does not itself specifically influence the "state of the art" and safety research. In doing so, it is dependent on cooperation with an ecological *community* of technicians.

There are quite a few approaches to an expert culture of this kind in industry and technology today. Safety, environmental protection, waste disposal and recycling have long been a way of doing business; and the more environmental awareness increases throughout the world - there is a clear trend towards this - the more environmentally friendly products create export advantages. For engineers, this results in a wealth of attractive and challenging technical tasks. Sometimes it can be observed how the old self-confidence of the scientifically trained engineer is given a new foundation in environmental awareness in the face of the thumb rules of the practitioners. However, because safety and environmental friendliness can only be permanently stabilized as inherent characteristics of technical development - so far, technical environmental protection still has too much the character of an "additional technology" - it is difficult to imagine an ecological community of technicians as a self-consistent community capable of conflicting with powerful interests.[69] Without strong public pressure, the chances of environmental protection are not good: this statement can be made with great certainty on the basis of previous experience.

Especially in the context of environmental awareness, there is no reason to despise technical imagination: Far more than staring at social structures, it opens our eyes to the variety of possibilities for saving resources and reducing emissions. Carl Amery was right to emphasize that the environmental movement is by no means hostile to technology,

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but, on the contrary, sought to bridge the gap between the "two cultures" denounced by Snow in 1959: the literary-humanities culture on the one hand and the natural and technical sciences culture on the other. "Since 1970 [...] my circle of friends and acquaintances has changed completely, and [...] almost exclusively through newcomers from the scientific and technical culture." According to Klaus Traube, the former technical director of Brüterbau, the attitude that has spread in the Federal Republic of Germany since the 1970s is not one of machine storming, but rather a disenchantment with technology and a "lifestyle that one could rather call sovereign leisureliness". The fascination with technical super-projects seems to have little appeal to the Germans, who have felt the curse of megalomania like no other people in this century and have realized more than many project developers that they live in a small, densely populated and vulnerable country. When the *Financial Times* asks whether the Federal Republic is becoming the "slow man of Europe", this prospect need not worry us.[70] As history shows, slowness is not necessarily a disadvantage; rather, it offers the opportunity to turn technological development into a social process. It seems that only in this way can technology co-evolve with human needs.

6. German paths and dead ends in the history of technology in the GDR

In 1985, Dietrich Staritz came to the overall conclusion in his *history of the GDR*, which was considered a standard work at the time, "that the GDR - at least in comparison to the CMEA - was successful with its economic policy orientation towards international economic and technological developments".[71] At the time, even Western anti-communists had been warning for decades that the GDR was training many more engineers relative to the population than the Federal Republic (which was no longer true in later times) and would therefore overtake the West in technology in the long term. Since the Sputnik shock of October 4, 1957, this has even been true for the Western view of the Soviet Union, and not only in space travel: even prominent observers took it for granted that this was an indicator of the entire breadth of the technological level. In 1957, the by no means Soviet-friendly sociologist Helmut Schelsky described it as an "obvious fact that automation had so far been carried out most successfully and to the greatest extent in both the USA and the USSR [...]. "[72]

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No wonder that even many clever and critical minds in the East were carried away by the space travel euphoria. In Christa Wolf's novel *The Divided Sky* (1963), which revolves around the building of the Berlin Wall on August 13, 1961 in a manner that was quite courteous by GDR standards at the time, a first deep rift arises in the relationship between the heroine Rita and her boyfriend Manfred (who then goes to the West) because Manfred is completely unreceptive to the ecstatic euphoria that overcomes Rita at the news of the first manned space flight. The future-oriented enthusiasm for technology of communism versus the trivial limitations of capitalism! The technological "Germany awakens!" literature of the Federal Republic of Germany also thought along similar lines. The SED leadership was always able to rely on Western sources for its confidence that technological progress would work for socialism and the centrally planned economy.

After the Wall came down on November 9, 1989, the scene changed abruptly. Now that Western observers were no longer just strolling along Unter den Linden with a view of the East Berlin television tower, but were swarming into every corner of the GDR and entering not only showcase factories but also dilapidated buildings, the impression of the completely outdated and run-down state of East German industry was overwhelming. The technology historian felt as if he had been transported back in time on a ghost train; a large part of the GDR looked like an open-air industrial museum. At Christmas 1989, Die *Zeit published* a report by Dirk Kurbjuweit on a visit to the Zwickau Trabant factory, VEB Sachsenring, under the title "Museum für Marx-Wirtschaft" (Museum of Marx's Economy). The Westerner experienced the small door that led into the car body factory like "the sluice gate of a time machine": "a leap of at least twenty years". "The first thing you notice: People, masses of people, welding, screwing, balancing, talking. [...] Metal rattles against each other, hammers roar, welding torches hiss. The noise is deafening, the air is sizzling." The gearbox of a rotating platform on the production line is broken, and - unbelievably! - for ten years, so that "the platform rumbles like a Trabant on a dirt track. During this bumpy ride, the men have to weld tiny threaded plates to the front wall of the Trabi. "[73] The journey into the past becomes a nightmare.

Suddenly it seemed appropriate to stylize the technological history of the GDR, like the entire history of the GDR, into a grotesque. Günter Gaus, once editor-in-chief *of Der Spiegel* and then the first head of the Permanent Representation of the Federal Republic of Germany in the GDR, had asked with concern years before the fall of the Wall: "Are West Germany's powerful supporting reunification with VEB and LPG?" Five months after the fall of the Berlin Wall, the Spiegel *editor* Dieter

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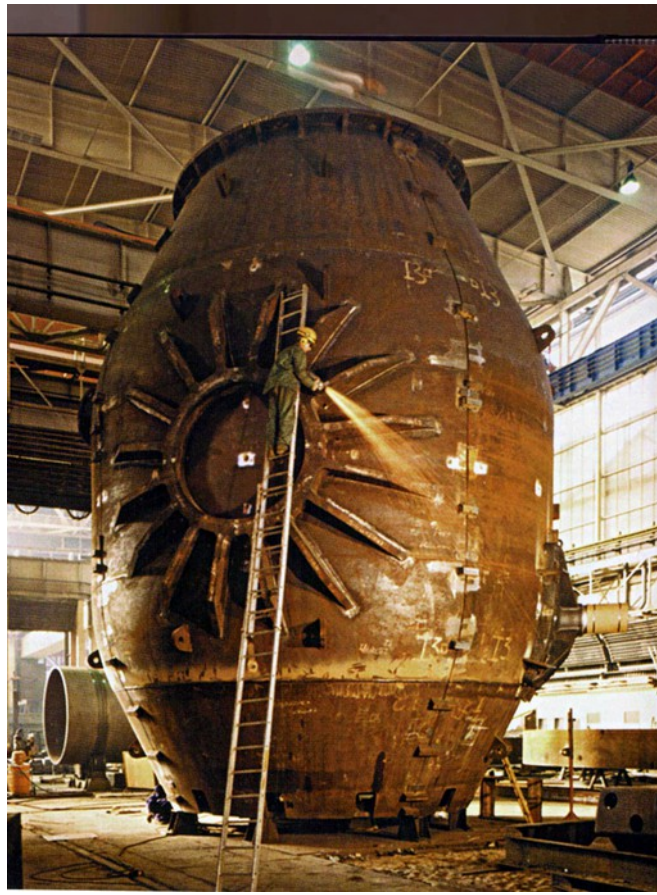

Figure 41: Converter for the steelworks built by VOEST-Alpine in 1984 in Eisenhüttenstadt, the former Stalinstadt: the "First Socialist City" of the GDR, built from 1951. It was the first and only steelworks in the GDR to use the oxygen blowing (LD) process, which VOEST-Alpine had already introduced 32 years earlier in Linz and Donawitz. A blatant case of East German backwardness? However, as the steel industry in the GDR remained dependent on scrap for a long time due to a lack of domestic iron ore, which could only be smelted using the Siemens-Martin process, the GDR behaved rationally when it stuck to the old process for the longest time.

Wild about this "delusion" and was stunned that, despite a worldwide flood of information, no one had apparently noticed "that the Central European industrial state of the GDR - not Outer Mongolia - was growing into an economic ruin that was poisoning its citizens" and that the Politburo was "a casket of the mentally deficient".[74]

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You have to remember this bizarre change of perspective when writing about the GDR - you have to look at the year of publication for any literature you use. No other topic in the history of German technology - not even the history of nuclear technology - is as difficult to present even reasonably objectively as this one. To this day, the question of value standards remains completely unresolved: How do you measure the course of events in the GDR? Against the Federal Republic - as GDR citizens increasingly did - or better against a comparable Eastern Bloc country such as Czechoslovakia? What was absurd in terms of the world market could still be reasonable in terms of the conditions and needs of the GDR75 - although even Ulbricht set the "world level" as a goal in his later years, and that meant in plain language: Western level. What possibilities did the GDR have in terms of its resources; were there missed opportunities or was the constraint of the circumstances overwhelming?

Well, the historian is not a judge of the world. As with all phenomena in history, his first and foremost task with regard to the GDR is to *understand it*: to understand the GDR from the perspective of its time and its historical situation. And of course it does not contribute to this understanding if the GDR is portrayed as a freak governed by half-idiots. In this way, one also learns nothing from this historical experience. It is important to remember that the industrial and technological policy of the GDR was largely based on fundamental ideas that were linked to successful German traditions and were also widely recognized in the West 30 or more years ago. The fact that creative power does not only stem from competition, but also from cooperation, the "community", the exchange of experience, the security and "joy of work" promoted by social security and recognition as well as internal co-determination - an old German favorite theme! - has been a fundamental conviction since the 19th century that distinguished the German path to modernity from the American one, even if many German business people admired the USA. It was and is not wrong that competition not only stimulates top performance, but also causes a lot of wasted energy, wasted resources and unnecessary duplication of work. And a certain leisureliness is often more beneficial to the quality and solidity of technical "development" than the competition's rush.

The state economy in Germany also has a long tradition dating back to the mercantilism of the 18th century: not always economically successful, but often innovative, especially in technical terms. "Only the state manages for eternity", said Heinrich Cotta (1763-1844), one of the founding fathers of forestry science, in response to those who pushed for the privatization of forests.[76] Certainly, this is not always and everywhere true; but

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The economy's dependence on private shareholders is even less of a guarantee for sustainable economic activity these days. Something that is easily forgotten today: The VW Group was state-owned in its greatest boom phase, and the same applies to the Austrian steelworks in Linz and Donawitz, which first introduced the oxygen blowing process named after them, the greatest innovation in steel production of the 20th century. State ownership as such did not condemn the industry of the GDR to technical stagnation!

To this day, despite the sneers of the innovation monomaniacs, it has often paid off far better in German industry to continue developing tried and tested traditional paths than to jump on the latest American high-tech bandwagon. Incidentally, technology based on science and qualified skilled labor was regarded as the German way; and in the entire education system of the GDR, technology ranked far higher than in the old Federal Republic, where the humanistic tradition continued, much to the anger of many natural and technical scientists. The fact that the increasing scientification of technology and the trend towards large technical systems worked in favor of central planning and state technology policy was also the prevailing opinion in authoritative circles in the Federal Republic for a long time.

The fiasco of the GDR is all the more puzzling. The Marxist dogma had prevailed there that the progress of the productive forces - and by that was meant specifically technology and technically trained people - would break the shackles of individualistic-capitalist production relations as a matter of inner law. In the course of the collapse of the GDR, the same pattern of thought spread among the scientific-technical intelligentsia in East Germany, but with the opposite point: since the beginning of the Honecker era, the "scientific-technical revolution" - often abbreviated to "WTR" - had been shamefully neglected in the GDR, and so in the end the productive forces in the era of the digital revolution had broken the rigid GDR relations.[77] Even Günter Mittag, the most powerful man in the economic management of the GDR until October 1989, played the dissident after his removal from power, whose WTR wisdom and insight into the revolutionary power of microelectronics was opposed by his opponents at the top of the SED as the "devil's work".[78]

But doesn't that turn things on their head; *hadn*'t the GDR leadership been literally obsessed with technical progress since the 1950s, *hadn*'t it recognized the enormous innovation potential of electronics in principle since the 1960s and constantly passed new resolutions to promote it? Was this fixation on the latest technical superlatives the fundamental error, and had Manfred, Rita's unfaithful friend in the
"Divided Heaven", hit the crux of the matter: that the GDR leadership

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who - staring spellbound at the space flight - neglected the broad basis of everyday technology on the ground?

In 1975, none other than Jürgen Kuczynski, the grand seigneur of East German historians, who in the early years of the Honecker era temporarily advanced to become the chief ideologue in matters of WTR, railed that "some" in the GDR were "above superficial chatter about the alleged implementation of the scientific and technological revolution, which will be an enormous task for many, many decades", that "some" in the GDR had "neglected the continuation of the third industrial revolution" - in his historical model of the electrotechnical revolution - "over superficial chatter about the alleged implementation of the scientific-technical revolution, which will be an immense task for many, many decades. A realistic warning at a time when the majority of GDR citizens did not even own a telephone! In 1979, however, he reaffirmed his loyalty to communist tradition by insisting that it was precisely in the era of electronics, which was causing growing unemployment in the capitalist countries, that "the prospects for scientific and technological progress" in socialism were "becoming ever brighter".[79] In the following years, a new, final era of forced promotion of electronics began in the GDR.

Based on what we know today about industry in the GDR, there is another hypothesis to explain the failure: The constant new campaigns by the SED leadership to push new technologies do *not document* effective control of real development, but are precisely the opposite, a reflection of the fact that the planned economy of the GDR contained little pressure to innovate, and that the planned targets - which were of a quantitative, not qualitative nature - de facto encouraged companies to continue producing as before and not to engage in risky innovations with lean periods. Precisely because innovations were not routine and the economic system had no inherent urge to innovate, special campaigns and new companies were always needed to drive innovation forward. For example, a separate industrial complex had to be established for semiconductor production.

However, this was not a suitable way to integrate semiconductor technology - in line with the German tradition of "Combi-Tech" - into the traditional world of technology. To the outside world, the GDR system appeared totalitarian, which is why Western GDR literature tended to take SED party conference resolutions very seriously and assume that they would actually be consistently implemented. However, as with the analysis of Nazi-German conditions, the totalitarianism model is only of limited explanatory value. Party conference resolutions often seem to have been self-sufficient as rhetorical proclamations, especially in matters of new technology; there was a lack of instruments for their effective implementation. As Werner Hartmann, head of the microelectronics department from 1961, sighed in his memoirs: "Always

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Again he had to recognize that resolutions and directives were seen as an end in themselves!"[80] "Large innovation projects played", as Hans-Liudger Dienel notes, "an important role not only in legitimizing the socialist state and its economic performance, but also in particular the new planning and decision-making structures [...]"[81] That is precisely the point: with this legitimizing function they often played out their role, even without effective practice following.

In the 1960s, "cybernetics" was Ulbricht's favourite topic for quite some time; his later much ridiculed slogan "Overtaking without catching up", which he issued at the Politburo meeting on 28 November 1968, was based above all on the vision of a GDR-specific path to cybernetics.[82] It was characteristic of the GDR leadership that it preferred to understand the new electronics as cybernetics, not computer science. The progress of control technology promised the final victory of the planned economy (until cybernetics became suspect after the "Prague Spring" of 1968 due to the potential it contained for self-control without control from above); but the entire GDR discourse on cybernetics seems, on closer inspection, strangely insubstantial: very often it is hard to recognize what is actually meant by "cybernetics".[83] "Electronics" was also an ambiguous term for a long time, into which many things could be projected - in the East as in the West. Party conference commitments to electronic WTR did not mean that anything effective was actually happening in this area. Instead, buzzwords such as "cybernetics" and "electronics" the illusion that making the planned economy of the GDR more effective was essentially a technical problem and had nothing to do with a liberalization of the system.[84]

At the beginning of the history of technology in the Soviet Occupation Zone/GDR, when great innovations were not even a thought, there was the grotesque attempt to activate the "productive power of man": in the person of miner Adolf Hennecke, who exceeded the daily target by 380 percent in a coal mine near Oelsnitz on October 13, 1948. He was a communist reincarnation of Taylor's model worker Schmidt, but with the difference that Hennecke's Herculean achievement - in truth a show deliberately prepared from above - was towering above what an average worker could achieve under normal conditions, even with good will. Hennecke made himself - no wonder! - Hennecke made himself hated by his buddies, who torched the car he had been paid for. Increases in labor standards were the impetus for the uprising of June 17, 1953. Officially, Hennecke remained a cult figure in the GDR for the rest of his life; but it was clear that the "dictatorship of the proletariat" with Hennecke methods lost all credibility. The GDR leadership was all the more dependent on the technical increase in labor productivity. Broadly speaking, three phases can be distinguished

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The two periods are characterized by the fact that the promotion of technical progress - as it was understood at the time - was pursued with major campaigns.

The *first phase* began around 1956 and culminated in the time of the Sputnik euphoria. It was the same time in which technical innovations became a major topic and political issue for the first time in the Federal Republic of Germany - after the end of the reconstruction phase. The GDR five-year plan for the years from 1956 to 1960 proclaimed the "scientific-technical revolution" as a goal for the first time; in concrete terms, this meant automation, nuclear energy, plastics chemistry and the establishment of the country's own aircraft production - at a time when the Federal German Trade and Industry Council doubted the benefits of this industry for the country.[85] The Rheinsberg nuclear power plant was commissioned in 1956: This put the GDR years ahead of the West German nuclear industry - but only in terms of project planning, not in reality.

In the Sputnik year, the "Trabant", the people's car named after the earth satellite, went into production. Although its thermoset body, which was later much ridiculed, was opposed from the outset by car technicians who had sworn by iron, it was nevertheless in line with the progress from metal to plastic, which was also widely believed in the West. Initially, the "Trabant" attracted international attention; only later did the "racing cardboard" become the butt of jokes.[86] From 1956, the "Schwarze Pumpe" combine was built, by far the largest lignite refining complex in the world: this gigantic project, whose roots went back to the Nazi autarky policy, absorbed more than half of the GDR's total investment funds at times.[87]

In November 1958, the Chemistry Conference of the Central Committee of the GDR met in Leuna under the motto: "Chemistry gives bread - prosperity - beauty", at which Ulbricht gave a day-long speech, the text of which runs to 60 densely printed pages. All in all, a classic manifesto of panchemism that IG Farben advertising could not have devised any better! The SED leader was obviously very committed to this topic and had familiarized himself intensively with the subject matter. In his eyes at the time, the GDR was particularly predestined for chemistry: "There will hardly be another country in the world that has such a high share of chemistry in total industrial production as our republic with 14.5 percent. "[88] Particularly noteworthy was his announcement that, contrary to the international trend towards petrochemicals, the GDR would also pursue the further development of coal chemistry.[89] One gets the impression that the IG Farben Group - officially the epitome of evil - was the secret role model of the SED leadership's industrial and technology policy at the time. The GDR film "Council of Gods" (1950) about IG Farben's collaboration with the Nazi regime,

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but also with Standard Oil, concludes with the happy ending, as the IG Farben researcher Dr. Scholz joins the front of the working class to the jubilant strains of Beethoven. There is no doubt that Ulbricht would have welcomed it if many IG scientists had followed this example.

The great maize campaign began in the countryside in 1956, inspired by Khrushchev. The "corn enthusiasm" became a question of socialist consciousness (however, a German Corn Committee was also founded in Bonn in 1956 on the orders of the Federal Minister of Agriculture); Khrushchev's core slogan that corn was "the sausage on the stalk" became the refrain of a hit song; in the propaganda, corn cultivation acted like a weapon of war. As was to be expected, fertilizer use and soil depletion were not an issue.[90] As Stefan Merl notes, Khrushchev's agricultural policy was essentially nothing more than an "ecological gamble": Things went well in rainy years, but a drought followed by catastrophic erosion damage accelerated his downfall.[91]

In the GDR, the first big start in future technologies lost its momentum after a few years. The ongoing mass exodus of skilled workers to the West until the Wall was built on August 13, 1961 thwarted all plans. At the beginning of the 1960s, when the global nuclear euphoria of the 1950s had fizzled out, the GDR abandoned its plans to set up its own nuclear power industry. In 1960, Ulbricht declared that there was no energy shortage thanks to domestic lignite, and he subsequently gave a brusque rebuff to the ambitious plans of the head of the Rossendorf nuclear research center, the former German-British nuclear spy Klaus Fuchs, for the GDR to develop its own reactor or even breeder reactor: the GDR lacked the industrial basis for this, and it would only be at the expense of the population's standard of living.[92] This was undoubtedly realistic; not even the Federal Republic of Germany was able to sustain independent reactor projects in the long term. Internally, the GDR leadership was more sceptical about nuclear technology than could be seen from the outside.

In the emergency situation of 1961, it also abruptly ordered the abortion of the development of an independent aircraft industry in the GDR, which had previously been pursued with much fanfare. For ambitious engineers, this decision was a traumatic experience.[93] From then on, the claim circulated - openly in the West, subtly in the East - that the SED leadership lacked technical expertise. In truth, the aviation ambitions of the small GDR had been ecologically nonsensical, and the relevant GDR policy had - as Hans-Liudger Dienel showed - rather suffered from an "excessive influence of the engineers".[94] Something similar can be seen in the early nuclear energy policy of the GDR. Ulbricht was more faithful to science than Adenauer. Only if the Soviet Union had agreed to turn the GDR into the high-tech workshop of the

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If the nuclear and aviation projects had made sense, the Soviet Union would have wanted to become and remain the workshop of militarily relevant cutting-edge technology for the entire Eastern Bloc. The GDR had hoped to eventually get its hands on its own uranium deposits - the largest in Europe - which the Soviets had laid their hands on, and thus achieve nuclear self-sufficiency; but here the Soviets remained implacable, and the GDR felt to the end that it was a defeated country.

Ulbricht remained a believer in science until the end of his rule. The construction of the Wall gave the GDR leadership new planning security; at the same time, the Soviet influence on technical development became stronger as a result of the closure to the West.[95] From around 1966 - again in sync with analogous trends in the Federal Republic - the GDR made a *second foray* into high and future technologies. Now came the real heyday of the WTR doctrine. To this day, the late Ulbricht era is considered a particularly promising time by technology scientists in the former GDR. More than before and after, it became the prevailing party line that certain particularly technically advanced sectors were the driving force behind overall economic development and therefore deserved special support, even at the expense of conventional industries.

Electronics, once frowned upon, became one such key sector. Ulbricht declared at the VII SED Party Congress in 1967 that future developments would be "characterized by electronics penetrating all areas of production and [...] changing the technical basis of the conventional branches and the production profile of the entire industry "[96]: an insight that sounds prophetic today, at least in this general form.

"Scientificity" became the magic word.[97] At a time when the Federal Republic of Germany's nuclear research was setting the signals for "big science", the GDR also attempted to enter large-scale research, even showing the ambition to distinguish itself as a pioneer among the CMEA states.[98]

A pioneer of this WTR era, in the construction industry and beyond, was the architect Gerhard Kosel, President of the GDR Construction Academy. He obsessively preached the rise of science not just as *a* productive force, but as the *most important one*; and for him, "scientific" in the construction industry specifically meant the cast concrete slab assembly construction method with serial and flow production methods. Coming from the Bauhaus milieu, he found his highest urbane ideals in the Stalinist neo-steel cities of Magnitogorsk and Novokuznetsk. His abhorrence of all "craftsmanship" is combined with a blazing hatred of his father, a plumber and fitter. For him, the most glorious technology was rockets, as they most perfectly embodied the fusion of science and technology. However, he lost influence,

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when it emerged that his "scientific" construction was more expensive than previous methods, his designs were oversized and reinforced concrete did not offer a solution to all construction problems. From then on, he could be annoyed that while ritual lip service was paid to the "WTR", everyday industrial life was far removed from it.[99] In "The Sorrows of Young W.", Ulrich Plenzdorf quotes the verse: "He who has nothing and who can do nothing, goes to construction or to the railroad." The monotonous prefabricated slab construction method with full-month days that prevailed in the GDR from 1970 onwards had little to do with modern "science" - it was nothing but the old Fordism in its purest form. In GDR jargon, the dwellings in these residential silos were called "workers' lockers".

The high-tech start-up of the late Ulbricht era also lost its momentum after just a few years. It proved impossible to achieve a noticeable improvement in the economic situation in this way.[100] Ulbricht, who was otherwise less likely than his successor Honecker to be fooled by Potjomkin's villages, increasingly lost touch with reality in his technological visions. In August 1970, he trumped Brezhnev and the Soviet leadership in Moscow: "By the beginning of 1971, we will implement automation in 80 combines. This is a new step that requires new scientific and technical knowledge, which we must apply consistently. [...] Dear Comrade Leonid! Be completely reassured! [...] Cooperation with the Soviet Union will continue to develop. [...] We want to develop in cooperation as a genuine German state. We are not Belarus, we are not a Soviet state. In other words, genuine cooperation. "[101] At the end of his reign, a commitment to the German tradition of highly developed scientific technology!

Brezhnev, however, does not appear to have been at all reassured by this challenging German self-confidence. From then on, latent opposing forces in the GDR leadership gained support in Moscow: this is how Ulbricht came to fall. In 1971, there was talk in the Politburo that Ulbricht represented "unrealistic, pseudo-scientific, partly technocratic theories "[102] and neglected "proportional development". Horst Sindermann was furious: "Should we say nothing at all about the production of consumer goods [...], just talk about robots? "[103] This was the background to Kuczynski's subsequent attack on the "superficial chatter about the alleged implementation of the scientific-technical revolution". In fact, there was only talk of the "WTR" - and many Western observers were deceived by it; everyday life in the GDR looked very different. Against this backdrop, Honecker's new line of downgrading ambitious technology projects in favour of consumer goods production under the motto "unity of economic and social policy" would have made perfect sense - if the economic and social policy of the GDR had not been so ambitious.

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system of the GDR would have been able to react flexibly to consumer needs.

But this system became even more rigid in the 1970s: many small craft businesses that had survived until then were nationalized; even Günter Mittag, looking back after reunification, described the loss of independent craftsmanship as a serious mistake.[104] It was a typical outgrowth of traditional progress clichés about the "inevitable demise of craftsmanship" in the modern age. In the countryside, the remaining remnants of the rural economy fell victim to a new wave of centralization, whereby - even surpassing analogous developments in the West - agriculture and livestock farming were separated from each other and transformed into industrial-like mass enterprises.[105] The technocratic basic trait of the SED dictatorship was revived precisely in the worsening crisis of the GDR economy. Trivial everyday technology was neglected. After the Wall came down, Central Committee member Günter Schabowski was particularly impressed by how easy it was to open and close drawers in a Western furniture store: The GDR had not managed that in 40 years.[106]

Third and final phase: In the 1980s, the "electronic revolution" gained a fascination like never before - in this respect, the GDR was no different from the West. As a matter of course, the GDR concentrated all its ambition on the hardware and its core: the chips, not on the software, the programs, which would not have been a suitable field for central planning.[107] Similar preferences were also held for a long time in the "predominantly hardware-oriented engineering world" of the Federal Republic108 ; in the SED dictatorship, which had increasingly become a "rule of the old men", an attitude had become entrenched that had originally characterized both German states. In the end, the GDR's enormously expensive chip development came at the expense of the computerization of machine tools, the beginnings of which had been successful in the GDR.[109] Only this type of Combi-Tech: the integration of microelectronics into machine tool production, could have kept this once most valuable export branch of the GDR at its old level. Instead, as Dolores L. Augustine writes, the microelectronics program became a "black hole that swallowed up ever-growing sums of money and did much to bring the GDR to the brink of bankruptcy".[110]

Western sociologists, led by Peter C. Ludz, once constructed a technologically oriented "counter-elite" for the GDR, on whose non-ideological rationality one could hope and whose leading exponent was considered to be Günter Mittag,[111] who was stylized as the evil spirit of the old system after reunification. Others made Erich Apel, the GDR

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economic reformer of the early 1960s, who - pushed to the side by Mittag - took his own life on December 3, 1965, became the tragic embodiment of a playful alternative: with the end of this one-time Peenemünde rocket technician, the successful GDR launch into electronics had also died.[112] However, it is doubtful whether Apel would have won the day if he had been more rational; at the 1958 chemistry conference, he had called for the universal use of radioactive isotopes in chemistry and railed against procrastinators who "hide behind safety regulations".

What is generally striking in the broad overview of GDR history is that the three phases of accelerated technical progress described above did not correspond at all with spurts of innovation in politics and society, but rather with severe spurts of the progressive paralysis that ultimately led to the downfall of the GDR. Technical progress functioned almost as a substitute for progress towards democratization and humanization! Discussions about a reform of the centralized planning system, which had arisen in the course of the "thaw" era after Stalin's death, were rudely stifled by Ulbricht in 1957. Reformist impulses from the Dubček era in Czechoslovakia and from the New Left in the Federal Republic of Germany that spilled over into the GDR fared no better in 1968. In the 1980s, the SED leadership's isolation from the Soviet Union sealed the deal.

"Perestroika" the fate of the GDR.

The ever new attempts at the "scientific and technological revolution" that was supposed to lead socialism to completion were accompanied by repression that destroyed the vitality of socialism. While the SED leadership had believed for a long time that electronic "cybernetics" worked for the centrally planned economy, it eventually emerged that the triumphant advance of microelectronics and the information and communication technologies based on it had played no small part in shattering the SED dictatorship. In the West too, however, the illusion that "electronic brains" could generate a reason that did not exist in human brains and bring about rational control of society was rampant for a long time. In many respects, the history of German technology during the period of German unification can be written as *a* history after all! And of course it is not just a German story.

Since the fall of communism in 1989 at the latest, it has been obvious that the GDR was a very German state in its own way and that the Sovietization, which seemed so overpowering to the outside world, did not reach into the brains. Even Ulbricht had an almost exaggerated respect for German traditions of "scientific" technology and large-scale industrial organization. Not only the history of the old Federal Republic, but also that of the GDR provides information about the strengths and weaknesses of German paths in technology.

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The technological history of the GDR by no means consists solely of a chain of failures, but also contains a number of promising episodes, typically where successful German traditions were continued: for example, in the production of machine tools and printing machines113 and in Zeiss optics: "As the crown jewel of East German industry, Zeiss got whatever it needed to create and maintain an enviable research infrastructure" (Dolores L. Augustine).[114] Especially when it came to well-known top German industries that brought in foreign currency through exports, the GDR leadership was conscious of tradition. If the Federal Republic offered test cases for how German traditions could or could *not* assert themselves in the face of Americanization, the GDR represented a test case for how to define the German path in other ways and also determine weak points.

The socialist economy was not based on competition, but on the principle of solidary cooperation. This was in the German corporatist traditions of "community" and "cooperative": traditions that have proven to be quite effective in the past. But it seems that the GDR combines were only inadequate continuations of this tradition. Successful corporations contain a strong element of autonomy. In the GDR, however, the (theoretical) omnipotence of the state, combined with the increasingly dense network of spies of the
"Stasi", had a paralyzing effect on communication. In fact, many companies had to rely on themselves: They had to watch how they got by in the system of the planned economy and had their own, often hidden, methods for doing so. Behind the scenes, there was a similar tussle of diverging interests over industrial and technical strategies as in the Federal Republic; however, these divergences were less openly aired than in the West. It should not be forgotten, however, that the ideal public discussion of technical alternatives was also very rare in the Federal Republic! Incidentally, the German corporatism inherited from the late 19th century, where it was successful, did mitigate the competitive struggle115 , but did not completely eliminate the element of competition. In contrast, the GDR experience demonstrates the extent to which, despite the proverbial "German diligence", the pure law of inertia prevails even under German conditions without the sting of competition.

The SED leadership, in the tradition of Marxist-Leninist faith in science and technology, cultivated the German tradition of science-based technology - as we have seen time and again. In terms of the sheer number of graduates, the GDR did much more for technical education than the Federal Republic; Western observers have often noted this with concern. But it is precisely here that the GDR offers a lesson in the fact that you have to look closely in order to recognize what this

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tradition and the conditions under which it led to success. It seems that the SED leadership - following a very German tradition in this respect - greatly overestimated the value of formal, state-institutionalized qualifications. "Polytechnic education", school and university degrees are no substitute for performance incentives and practical experience in dynamic, technically well-equipped companies. The broad exchange of experience in industries and regional "clusters" was in all probability at least as important for the success of the "German production regime" as the formal qualifications of the employees. Wolfgang König has contrasted the "school culture" of German engineers with the "practical culture", *store culture* of their Anglo-American colleagues; however, the German engineering culture not only included graduate engineers, but also the "dual system" of broad vocational training, the combination of vocational schools and in-house training. Everything depended on the quality of the companies. But even in Germany today, the term "dual system" only conjures up images of waste separation!

GDR apologists tend to emphasize the CoCom lists, the Western high-tech embargo against the Eastern Bloc states, as one of the main causes of the GDR's increasing technological backwardness compared to the West. In contrast, more and more discoveries are being made about the eminent role played by the "Stasi" in spying on Western technology.[116] It is doubtful whether one or the other was a decisive determinant of technological development in the GDR. The decisive factor in industry is generally the broad basis of experience, not a specific detail, a specific research result. The Berlin Wall, through which the GDR sealed itself off from the West, was probably far more important than the Western technology embargo. Since then, there has been a lack of a lively view of Western production, Western know-how and marketing.

In the early days of the GDR, the reparations to the Soviet Union - in 1946 no less than 48.8 percent of the total social product of the Soviet Occupation Zone![117] - and especially the dismantling and the unequal trade agreements, were undoubtedly a heavy burden. In the long run, however, the most detrimental effect probably came not so much from what the USSR did to make life difficult for the GDR, but even more from what it did to make life all too easy for East German industry: the virtually unlimited market even for obsolete products that would have had no chance on Western markets. Deprived of US competition, which had been the stimulus for the German mechanical engineering industry since around 1900, this sector reverted in part to the conditions of the 19th century, when German mechanical engineers were told that they sold their products by weight and could not be seen anywhere outside Russia.

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The "ton ideology" became a standing term among GDR critics: the planning specifications encouraged the focus of production on pure quantity, without much consideration for quality and differentiated consumer needs. Paradoxical as it may seem: In the GDR, which was closed off from the West, Fordist methods of standardized mass production were able to assert themselves more uninhibitedly than in the Federal Republic. In this way, the "Trabant", which in its early days also attracted attention in the West with its innovations, became a technical fossil and a symbol of the disintegrating GDR. When Günter Mittag concentrated the entire industry in "combines" at the end of the 1970s, which encompassed all stages of production, this was a reorganization in the Fordist spirit[118] that drove the process of ossification in GDR industry[119], while at the same time the trend in the West was towards the outsourcing of suppliers in the interest of increased flexibility, following the Japanese model. But, not to forget: Parts of German industry also adopted Fordist methods for quite some time, more than was good for them in the long run. As standardized mass production was particularly susceptible to crises and repetitive subcontracted work was the easiest to automate, this is one of the main reasons for the increasing mass unemployment in the West since the 1970s.

Back to the GDR: today, when the files are open, we can marvel at the sharpness with which many weaknesses of the GDR economy were recognized and named internally - especially in the Ministry for State Security[120] - without anything effective having been done about them. Particularly within technology, electronics had been superlatively emphasized as a key technology in East Berlin since the 1960s, when it was not a political issue of any priority in Bonn, and the importance of promoting it was repeatedly stressed. And yet, in the end, it was precisely this that became the most fatal cliff in the development of technology in East Germany! How can this paradox be explained? Certainly the fact that state technology policy could only advance a sector such as microelectronics, which gained its dynamism so strongly from users and their free communication, to a very limited extent. Under the GDR dictatorship, which patronized its citizens, modern information and communication technology inevitably had to lag behind in its development, even if major state projects provided important elements of the hardware.

There is probably another reason for this. Max Weber once declared, in his inaugural speech in Freiburg in 1895, that economics was a

The "science of man" asks above all about the "quality of human beings", who are "bred by the respective economic and social conditions of existence".[121] It seems that it is not only in the economic and social sciences that the "quality of human beings" is being questioned,

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but also in the history of technology, the type of person that thrives in a society is crucial.

The GDR dictatorship, which originally emerged from a party of revolutionaries, had in its later years become a "rule of old men": It was impossible to successfully develop a technology like microelectronics, which relied so heavily on a new, headstrong generation. In the West, the industry leaders had to be demonstrated everything that could be done with the PC "by long-haired freaks in sandals".[122] Günter Mittag was able to repeatedly and threateningly
call for an "electronic revolution": He and his subordinates were not the men to turn such words into practically effective deeds. At the X. At the X Party Congress of the SED in 1981, the slogan rang out: "Microelectronics - that is our barricade of revolution in the 1980s. "[123] But this traditional agitprop style was almost laughably inadequate for the new world of technology. Gerhard Barkleit recognizes a kind of "magical thinking" among GDR leaders when, shortly before the downfall of the state, the ceremonial handover of (allegedly) GDR-manufactured microprocessor components to Honecker was given epochal significance.[124]

Well, even in a traditional West German company like Siemens, the entry into microelectronics was not quick and easy. As long as Carl Knott ruled in the style of a company patriarch and - as the saying goes - the first commandment was: "I am the master, your Knott; you shall have no other Knott beside me", Silicon Valley types had no chance of getting into positions at Siemens. A Knott could direct the entry into nuclear technology, but not a successful entry into microelectronics. There were similar types of people on both sides of the German-German border; on closer inspection, there are counterparts in West German history for much of what is ridiculed today in the history of the GDR. The experiences of the GDR thus shed a sharper light on the dynamic elements that are necessary for the successful further development of German industrial traditions.

At the time when the GDR was investing billions in chip production that would have been needed elsewhere, Siemens in the West was also demanding state subsidies for the construction of a chip factory and threatening that otherwise the entire semiconductor production would disappear from Germany. The surprising turnaround came in 1992 under the new Siemens Vice President Heinrich von Pierer: Siemens abandoned chip production and lost interest in the corresponding state subsidies, as it had become clear that the latest chip generations were easily available on the world market. While the development of the chips had originally required a great deal of intelligence, it had been a mistake to conclude that routine

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chip production required a lot of intelligence: instead, this could take place in miserably paid assembly line work in India. Looking back on previous unfounded fears, the long-standing Siemens CEO Bernhard Plettner stated in 1994 at the age of 80: "The chance of bringing the world's electronics industry to its knees by making memory chips more expensive or scarcer, or of getting rich by raising prices, is zero." The chips are in the process of becoming a "mass product", "which in a few years will have hardly any other significance than a standardized screw".[125]

The magical fixation on chips had been irrational and the result of the helplessness of digital dilettantes! Instead, Siemens concentrated on application-specific semiconductors.[126] When a Spiegel *interviewer* reproached the 90-year-old philosopher Karl R. Popper for saying that Europe and the USA feared that "they were losing the chip war against the Japanese", he replied with the wisdom of old age: "All these problems are not to be taken seriously and should not be discussed in this way."[127] At that time, shortly before the first major slump in the Japanese semiconductor industry, Konrad Seitz, long-time head of planning at the Foreign Office in Bonn, predicted, still very much in the style of the technological "Germany wake up!" literature, that without massive support for the chip industry and other high-tech, Europe would become a "technological colony" of the Japanese and Americans.[128] As can be seen, there were astonishingly similar thought structures in the East and West when it came to "technology policy".

The deeper reason for the GDR's fiasco was probably that SED rule was a dictatorship imposed by an occupying power. It retained this odium until its end: We have seen through this more clearly since 1989 than before. Such a regime can do whatever it wants: It is always wrong somewhere. Therefore, the significance of the details of technology policy for the fate of the GDR should not be overestimated. The history of technology is also part of history as a whole.

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Homo faber, homo ludens, homo sapiens - and the question of synergy

In search of the history behind the stories. When people talk about technical innovations today, they no longer think first and foremost of locomotives, as they did a hundred years ago, but of computers and the Internet. As early as 1973, Georges Elgozy, technical advisor to the French government at the time, wrote that "no machine in human memory" had "given birth to more utopian fairy tales than the computer". For decades, the "electronic revolution" has been used as an argument for all sorts of things: to justify irrational corporate strategies as well as to excuse entrepreneurial fiascos, and time and again to call for state subsidies. And then there's the Internet! Today, the topic of the "Internet" has become more omnipresent than any technology topic in a long time, even in everyday conversations - people can no longer imagine a world without the Internet and almost forget that this new medium with its unprecedented wealth of information has only been around for just over a decade. Even older people struggle to remember how they once managed without computers, e-mails and the *world wide web*.

But what kind of history is this, the global rise of this new world of technology: where does it begin, what is its essence, what does it prove, how does it change the previous picture of the history of technology? Are there still prominent founding figures here or just a stream of development without individual actors? Are the personal stories no longer the true history? And does the question of national paths still make any sense here? Never before have such different stories circulated about a technical innovation, some of which have hardly any relation to each other: Stories of theorists and experimenters, scientists and hobbyists, military and civilians, Americans and Japanese - of calculating machine inventors, semiconductor pioneers[1], American rocket engineers, particle accelerators at CERN in Geneva[2] and up-and-coming garage entrepreneurs. The triumphal march of the computer demonstrates the paramount importance of promoting basic research for some, the key function of cutting-edge military technology for others, and the creative power of market-oriented entrepreneurial pioneers with a feel for the very latest dreams of potential buyers.

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have. This jumble of stories is initially daunting for the historian, but at the same time it makes us realize that these very latest technological developments, which are taking place before our very eyes, are even more urgently in need of critical research into the history of technology today than the history of the old steam engine.

After decades of criticism of technology, the triumph of the personal computer and the Internet has given rise to a new belief in the irresistibility of technological progress. But it is precisely this story that demonstrates, more than almost any other major innovation push before it, the surprising zigzag with which the "progress" of technology can turn the corner. And yet it is precisely this insight that has threatened to be systematically blurred by the relevant literature for some time now: The swelling stream of computer and Internet stories tends to straighten out even this story syndrome with its coincidences and bizarre twists and turns into linear, quasi-organic evolution.

However, this can only be believed by those who do not remember very far back in time or who have too thoroughly refreshed their memories. After all, the joke of history is that it was constantly accompanied by false predictions and that something always came out that hardly anyone involved had foreseen.[3] Even IBM boss Thomas J. Watson assumed in 1943 that there was only a need for a few computers worldwide! In the 1960s, a computer in the Federal Republic of Germany still cost around 10,000 Deutschmarks a month to rent: Only large companies could afford that, and almost everyone was convinced at the time that it would stay that way.[4] Until the end of the 1960s, it was generally believed that there was a trend towards ever larger mainframes; at the time, the "municipal reorganization" with its history-less new combinations of synthetic cities was justified by the fact that previous municipalities would no longer be able to afford future mainframes. In the 1970s, Siemens and AEG were still planning a "mainframe computer union". What we can no longer imagine today: The decentralized use of computers had to be thought of first. Hardly anyone foresaw the PC. And even in the 1970s, when the PC moved into many workplaces, only very few people had any idea of the coming triumph of the PC in private homes.[5] Today, the term "computer" is a fossil from the 1970s, when people only thought of computers instead of word processors when they thought of this technology. And "electronic brains"! Computer scientist Klaus Brunnstein reminded us that the view of the computer as an "electronic brain" was a misunderstanding that has characterized computer science since John von Neumann, one of its most prominent founding fathers.[6]

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Homo ludens without a mask. "Interactivity" became the magic word thanks to the PC and the Internet. At a time when the old fantasies about human-like robots and "electronic brains" had long since gone out of fashion, the computer became a quasi-communication partner for humans like no other mechanism before it, triggering endless chains of interaction between man and machine, even seducing the passionate user to build a fantasy identity "online" and communicate as such a virtual being.[7] The most surprising moment from a historical perspective is the colossal role of *play* in the spread of this new technology. Young people discovered a practical value of this technology that the engineers who once developed it had not thought of. It was not infrequently for the sake of children that serious men acquired a computer for the first time.

On closer inspection, this drive was not entirely new in the history of technology. Even the inventors of the telephone could not have dreamed of the extent to which this device, which was first installed in offices and public offices, would become an indispensable tool for leisure activities[8] , to the extent that voices on the telephone sometimes sounded more erotic than in face-to-face communication. Toy trains were the most popular of all toys right up to the present day, and even grown men crawled around enthusiastically on the floor in front of them - but they hardly contributed to the further development of railroad technology. In this respect, computer mania did bring something new. Last but not least, the type of the honorable buccaneer plays a remarkable role in computer history:
"It was hackers who frenetically drove the introduction of PCs in the 1970s. "[9] Even earlier, before the era of electronics and even the Hollerith punch card machines, vending machine technology made significant progress through games. Mechanical music machines with perforated disks were successful in Germany even before punched cards.

And then there's the Internet! It seemed to promise unimagined riches; but how the Internet can not only be played around with, but also how big money can be earned, is still partly an open question. During the first "Silicon Valley fever" in the 1980s, many people imagined that in the new digital world you no longer needed any skills or qualifications to make big money: "Anyone, even an eleven-year-old girl, can be an entrepreneur. "[10] In the frenzy of the *New Economy* around the turn of the millennium, Internet companies sprang up like mushrooms, hoping to make millions by simply providing addresses and information - until the house of cards collapsed abruptly in 2001. This was because during these years, people realized what they had not yet realized in the mid-1990s.

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Figure 42: "The www world", *Spiegel title* from February 21, 2000, still at the height of the "hype" of the Internet companies. In the social sciences, too, the idea that the Internet was giving rise to a "global society" became common knowledge. The image is ambiguous in *the manner of* Spiegel: if you can control the world with the click of a mouse - can you perhaps also "unwind" it with the click of a mouse? After the great "crash" of the *New Economy* in 2001, several titles were designed for Der *Spiegel* with a mouse falling into a glass of water or tumbling down a waterfall; however, they found no favor with the editors-in-chief.

The fact that information can be obtained free of charge via the Internet in an infinite, constantly growing avalanche-like abundance. Out of sheer pleasure, exhibitionism and the urge to create a limitless public sphere, millions of people post information on the Internet without being paid for it.

Seen in this light, the era of information and communication technology is not - as we hear everywhere - an age of the "information society", but on the contrary an age of the increasing devaluation of information, which is now freely accessible to all. There is some evidence that, contrary to common assertions, we are not experiencing a "dematerialization" of the economy.

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We are not only facing a new economy, but also a new valorization of material goods that cannot be reproduced tens of thousands of times over with a single click and almost without energy expenditure, as information is devalued and raw material and energy prices rise. Above all, the Internet has given an unprecedented boost to the distribution trade.[11] SAP boss Hasso Plattner - in some respects a Nixdorf redivivus[12] as the new world market leader in business software - who confessed in 1999 that the success of Internet companies was causing him "endless" frustration - which was not to last much longer! - rightly reminded us that "the economy is still based on the fact that we design cars, computers, airplanes, houses, machines and other products, manufacture them, physically transport them to the customer and then bill them. "[13] The euphorics of the Internet economy had not foreseen the incredible extent to which a human instinct for play would run riot on the *World Wide Web* and unleash an enormous flood of information for nothing!

The Dutch historian Johan Huizinga already showed 70 years ago how playful, sporting drives can be recognized in the background of all of history - the history of culture and war, even the history of economics and science - at least in the history that starts with the agonal Eros of the Greeks - so in this respect it is not a fundamentally suspect tradition![14] In fact, the financial benefit of very many technical innovations could not be calculated at all at the beginning, and the inventors did not benefit much for themselves. But until the playful computer era, the big players in technology were generally concerned with a serious camouflage.[15] In this respect, it can be said that today a latent driving force of technology has become manifest. The urge for the *citius, altius, fortius* - the "faster, higher, stronger" was essentially a sporting ambition; this remained concealed as long as it coincided to some extent with economic rationality.

Or with - real or supposed - military rationality. In bomb and missile technology, the urge for the superlative could run riot unchecked for as long as the Cold War lasted or was resurgent, even when there was a lack of civilian demand, lavishly supported by state funds. And sometimes, by chance, there was also something for civilian technology. Whereas the Teflon pan once served as proof of the spin-off of space travel, today, when the military purpose of armament can hardly be credibly proven, computers and the Internet are far more effective in demonstrating the civilian benefits of cutting-edge military technology.

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Raubkopieren ist kein Kavaliersdelikt.
Es ist ein Verbrechen. So wie das Zertrampeln von Autobussen, das Zerfetzen von Flugzeugen in der Luft und die Freiheitsberaubung von Frauen. Ich bitte Sie daher, hier im Kino nicht zu filmen.

Figure 43: A cartoon in the computer magazine *c't* (*computer technik*) pokes fun at attempts to criminalize the pirating of cinema films with the threat of King Kong. The possibilities of modern copying technology threaten to undermine copyright - a sign that we are not only living in the "information age", but also in an era of the devaluation of information through its effortless duplication!

However, there are several ways of reading this story: it also shows that there was no direct path from military high-tech to marketable products; indeed, the mentality of the large-scale military research complexes tended to block the imagination for very civilian opportunities offered by the instinct to play. It was precisely Japan, which did not have a large military-industrial complex, that contributed decisively to the breakthrough of microelectronics. The role of the military in this history has elements of coincidence; there is no reason to derive from it a historical law about the key role of high armament for technological progress that legitimizes the continuation of the arms race beyond the Cold War. As long as the Internet was still a matter for the military and nuclear research, the public was not even aware of it.[16] In general, the triumphant advance of the PC and the Internet has all the characteristics of a historically singular event.

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It would be quite misleading to turn such innovation boosts into arbitrary, repeatable events, provided that the appropriate state funding is made available.

Silicon convergence between microelectronics and ecology? Technical innovations in the use of *solar energy* have also recently served as proof of the existence of the spin-off. Photovoltaics experienced its first and so far greatest triumph in the 1960s in space travel. There, unlike on the ground, it was even able to assert itself as an energy source against nuclear technology. In the decline of space travel that began around 1970, which lost its charisma after the successful moon landing, solar technology descended from space to earth, as it were, and sought new fields of application there. The "ecological revolution" of 1970 and the mass protests against nuclear energy that followed a few years later came at just the right time. Understandably, however, the - generally pacifist - German opponents of nuclear power and environmentalists did not really know what to make of this new potential ally for a long time, which came from the heart of the military-industrial complex and seemed like a foreign body in the "alternative" milieu, and whose most prominent and fiery advocate in the Federal Republic was Ludwig Bölkow (1912-2003), one of the founding fathers of the dominant armaments company Messerschmidt-Bölkow-Blohm (MBB), a driving force behind German space travel and a friend of Franz-Josef Strauß.[17]

Solar energy became Bölkow's retirement hobby. On his initiative, a solar-powered hydrogen production plant was built in the Upper Palatinate town of Neunburg vorm Wald in 1986, the year of Chernobyl, which was praised as the largest in the world, but was nothing by the standards of the energy industry.[18] In the years following Chernobyl, a wave of enthusiasm for solar energy rolled in.

"solar hydrogen energy economy" by the German public.[19] On August 11, 1987, Der *Spiegel* made solar hydrogen its cover hero, with the magazine otherwise famous for its sarcasm displaying an unaccustomed enthusiasm.

Particular fascination was aroused by the seemingly patent solution of paving the sun-rich Sahara with solar cells, splitting hydrogen from water there, thus supplying Europe with abundant and cheap fuel and at the same time doing something for the development of Africa. The idea as such was old and had entirely non-military origins; August Bebel had already expressed his enthusiasm for it in his program book *Die Frau und der Sozialismus (Woman and Socialism)* around 1900, and this vision was revived after 1986, particularly in SPD circles. But without any political and infrastructural basis, the Sahara Plan had something naive about it. And when the Neunburg solar plant produced hydrogen, it was not until

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It turned out that the fuel produced in this way was initially far from economical.

Therefore, it cannot be ruled out that the space complex, where money was no object, maneuvered the use of renewable energies into an economic cul-de-sac and in the end the oldest, but not at all noble, way of using solar energy proved to be the most practicable: firing with wood! As forests generally grow on land that is unsuitable for arable farming, there is far less conflict with food cultivation than with other energy crops. However, trees grow imperceptibly; if they are felled, they fall with a crash: this is why the "limits to growth" of wood, unlike oil, have always been exaggeratedly drastic, and the large-scale use of wood has been accompanied by fears of wood shortages for centuries.[20]

The era of microelectronics has pushed the old energetic image of technical progress, which dominated from the early steam engines to the premature nuclear revolution, into the background: Progress to "increase power", inextricably linked to increasing energy production and energy concentration. Instead, a new image of progress gained suggestive power: progress towards ever denser networking of the world, towards ever faster and ever more comprehensive communication, indeed towards the medium of human understanding and self-understanding. A large part of the history of technology could be reinterpreted retrospectively from this perspective. To some extent, this image of progress had already been around for a long time, since the time of the first railroads and telegraphs, and in fact it is much older than the energetic image of progress established by the steam engine: think of the enthusiastic 15th century eulogies to the "divine art" of printing, which opened up a new era of knowledge! Even the totalitarian dictators of the 20th century recognized from the outset how crucially modern power depended on mastering the information and communication networks of the time. However, earlier prototypes of technical communication - whether locomotives, the "power stations" with their electrical networks or the mass press with its immense consumption of cellulose - were generally associated with increasing energy and material consumption. It was only with microelectronics that the new image of progress could be decoupled from the old one.

Even Bernd Stoy, then Director of Energy Utilization at RWE, proclaimed the "decoupling" of economic growth from energy consumption in 1978 - albeit not without a frown from RWE's top management - and at the same time campaigned for the promotion of solar energy.[22] In this respect, a convergence developed between the electronic and ecological eras. The

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The oil panic in the fall of 1973, which initially seemed to be a great opportunity for nuclear energy, gave industrial energy-saving strategies a strong boost for the first time in a long time, and as a result, new and unimagined potential for increasing energy efficiency became apparent. Anyone who had previously believed that optimizing energy efficiency was an issue from long ago was proven wrong.

These experiences also shed new light on the history of technology to date: in terms of energy, the supposed technical progress had not been as rational as previously believed. The energy-saving perspectives soon took a good deal of the drama out of the energy situation. As in the Suez crisis of 1956, the
"Energy crisis" hysteria a false alarm. Solar energy enthusiasts are intoxicated by the idea that the solar energy hitting the earth is 15,000 times greater than the total energy consumption of mankind. "There is no energy shortage, only a fantasy shortage!"

The technology historian cannot quite share this optimism. Hardly any other economic sector in the world is so dominated by established power structures and infrastructures as the energy industry, including the associated transport and fuel industries. Not only does the law of eternal innovation prevail here, but also the law of conservatism anchored in structures, technology paths and fixed networks: this also characterizes the entire history of technology in the 20th century and even permeates the history of nuclear energy. Since the mere expectation of a coming energy shortage drives up energy prices and thus the profits of the energy industry, there is no pressure for change; quite the opposite. The fact that certain new energy conversion technologies are theoretically possible says very little about their real prospects. The history of technology by no means proves the existence of a law that the dreams of today are the realities of tomorrow.

In contrast to the electricity supply networks - until then the prototype of the "large technical system" - the Internet has provided a new type of network since the mid-1990s that hardly anyone could have imagined until then: a loosely networked system without a control center - at least without a control recognizable to the average user - in which the user could build his own network and communication forum at will. Until then, technical development had presented itself in two major divergent trends: the trend towards a large system and the other towards individualization and privatization. Microelectronics, like solar technology, uses the semiconductor properties of silicon: signs of a promising technical convergence between economy and ecology? All by itself,

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However, this is unlikely to arise from the logic of technology alone. In Silicon Valley, the environmental risk of disease is unusually high.[23]

Privatization of technology - the topicality of the old question of human needs. Is the Internet the beginning of a new era that combines the perfection of large technical systems with the maximization of individual freedom? But we must reckon with the possibility that this *coincidentia oppositorum will* remain unique in its kind. Even if the remunicipalization of energy supply on the basis of renewable energy sources succeeds, it will remain dependent on supra-regional grids for security of supply. The future ideal of using the railroads for private transport has been around since the time of the first railroads and has not come any closer to realization since then, even if electronic control theoretically offers new possibilities in this respect.

Even the most beautiful of all human technological dreams: to soar individually and smoothly and silently like a bird, has come no closer to being realized, indeed its technical absurdity has been exposed even more clearly. The Greek myth of Daedalus and Icarus always contained the confidence that the person who prudently kept his balance between heaven and earth would eventually succeed in flying; and in 1909 Wilhelm Ostwald still expected that "man will learn to fly just as well as the great seabirds do, which achieve enormous speeds without flapping their wings".[24] Today, this dream has come to an end; hang-gliders in particular feel the narrow limits of flying without an engine. The Bremen-based car manufacturer Carl Borgward, who in the late 1950s speculated that the car boom would be followed by an - albeit much more limited - helicopter boom, maneuvered his company into the most spectacular bankruptcy in history, not least due to the costly development of helicopters.

"Economic miracle" era.[25]

In other respects, however, the trend towards miniaturization and privatization of technology - once: from the tower clock to the pocket watch - is a major trend in the history of technology in the 20th century: from the railroad to the car, from the steam engine to the electric drive, from the cold store to the refrigerator[26] , from the wash house to the washing machine, from the exhauster to the vacuum cleaner, from the cinema to the television, from the mainframe computer to the PC. It opened up opportunities for gigantic mass production, allowed new sectors of the economy to expand and obviously coincided with a basic individualistic trait of human nature that even decades of communism were unable to eliminate in the slightest. This repeatedly confirmed the rule that products are not made marketable through "research and development" alone, but only through interactions between producers and consumers - a fact that particularly influenced the market success of electronic devices.

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The extent to which the huge growth spurt caused by this trend will be repeated in the future is doubtful, however. The industrial history of recent decades in particular shows how difficult it is to find new areas for mass production on a large scale.

For all those who do not want to know anything about "human nature", the question of human needs has long since become hopelessly old-fashioned: a question posed by people who have not understood that technology is an overpowering cultural phenomenon that does not need human needs to justify itself, but rather shapes people themselves. And certainly those moralists who once fought against "unnatural" luxury in the name of natural needs have hugely underestimated the potential contained in human needs: the "nature of man" is nowhere near as fixed as the natural rights activists believed until the 18th century. It contains potentials that were only gradually discovered. Even the non-car driver, who feels no passion for motorized speeding, cannot help but feel that the triumphant advance of the car was based on a human natural disposition: a desire for autonomous motor skills.

It would probably be a mistake to conclude from all of this that there is no such thing as human nature and that new needs can be created at will. In the wake of totalitarian dictatorships, the manipulability of human beings has been overestimated. Helmut Volkmann, Siemens' cross-headed in-house futurist, sees the cause of many undesirable developments in the economy in the fact that people - fixated on maximizing profits - have lost sight of the needs of people and society. This has led to the invention of models that nobody really wants: the car-friendly city, the deserted factory, the paperless office - "Who would think up such nonsense? "[28] It is doubtful whether the human need for ever new things and worlds is infinite. The drug philosopher Marshall McLuhan predicted the "end of the book age" *(The Gutenberg Galaxy)*; instead, the book business is one of the biggest beneficiaries of the Internet.

It seems that when it comes to innovation, the eyes have a different disposition than the stomach: the media are expected to present something new every day; restaurants, on the other hand, advertise with "old German cuisine" and other signals of tradition, even when it comes to exotic cuisine. This means that technical innovations only have a very limited chance. Or people don't make much of them. Today's brewery in Germany is a very modern branch of industry, the most successful industrial user of biotechnology based on microbiology to date - and yet the brewery, with its ritualized reference to the Bavarian Purity Law of 1516, drapes itself as a traditional industry dating back to the 16th century: so successful that

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they are usually completely forgotten in all the discussions about biotechnology! In Georg Simmel's *Sociology of the Senses* (1907), sight belongs to the higher senses, taste and sexuality to the lower ones; but Simmel certainly did not despise these lower ones, and the historian of technology, who is dealing with the trivial side of human existence, should do so just as little. Indeed, even for Nietzsche's *Zarathustra,* the highest attitude to life culminates in the affirmation of eternal recurrence. Permanent innovation, on the other hand, is not compatible with a full sense of life.

Today, the human need for innovation is at its most boundless where the fear of death - that fear which in principle can never be quenched - plays a role. *Medical technology* is one of the biggest remaining boom sectors in the history of technology in recent times - in Germany even more so than elsewhere, as long as health insurance companies paid for all therapies almost unseen.[29] The history of technology is still in its infancy. In general, real progress can best be assumed where the refinement of technology enables more gentle interventions in the body - provided this does not increase the surgeons' desire to operate, as was already the case with earlier advances in surgical technology. However, there is a certain regularity to the trend that the greatest technical effort is concentrated on intensive care medicine, which all too often only serves to prolong dying rather than life, and becomes unaffordable for the average patient or - since resources are not unlimited - almost inevitably comes at the expense of the care that improves the quality of life of the curable sick. Tricky ethical problems arise that would not have existed without the proliferation of intensive care medicine: should society spend a hundred times more on the prolonged death of the elderly than on the health education of children?

The age-old adage "prevention is better than cure" is undermined by medical technology in much the same way as the principle of emission prevention is undermined by elaborate "end-of-the-pipe" environmental technologies. The most impressive eye-catcher in the large German Occupational Safety and Health Exhibition (DASA) at the Federal Institute for Occupational Safety and Health in Dortmund-Dorstfeld is a scrap-melting furnace with a huge exhauster from the 1960s, which turned an occupational hygiene problem into an environmental problem. In general, technology contains a temptation to substitute problem solutions through problem shifts and problem metamorphoses: to transform visible smoke into invisible emissions, resource problems into energy problems, soil pollution into air pollution through waste incineration. Which is not to say that technology does not in principle also make preventive environmental protection possible!

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Peter Borscheid has described the entire history of culture since early modern times as a history of acceleration, the spread of the "speed virus". In the history of technology in particular, it makes sense to look for the common thread running through all the events of the last half millennium, from the old fulling mills and printing presses to the very latest lightning-fast electronics. But technology that is economically viable must meet human needs. To what extent will this be possible in the future through acceleration? Borscheid concludes his story with the indisputable statement that "a large part of the most beautiful hours of life" do not need "a clock" and that "the acceleration and speed system built up at enormous expense" has "already become a pure end in itself in many of its parts" and has "drifted into the absurd".[30]

People who used to write two letters a day have now become accustomed to answering around 20 emails a day - but whether they will have become accustomed to answering 200 emails a day in ten or 20 years' time is questionable. The old adage "There's a limit to everything" probably still applies. Certainly, new human needs have developed in response to the speed opportunities offered by new technology. The speed rush, already recognizable to some extent in the chase of earlier times, is perhaps the most significant anthropological novelty of the modern age (although, paradoxical as it may seem today, the bicycle played a by no means insignificant role in the discovery of this new drug). And yet, the elementary processes in the human body - whether heartbeat, breathing, sleep or digestion - cannot be accelerated very well: training yourself to do so is neither pleasant nor healthy.

The secret basic contradiction in the modern history of the relationship between technological trends and human nature seems to lie not least in the fact that the increase in speed thwarts the pleasure of sex. This basic dilemma can already be seen between the lines of countless patient files from the mental hospitals that sprang up like mushrooms towards the end of the 19th century.[31] The entire modern media world bears witness to the infinity of unsatisfied erotic desires. In the great crash of the breezy internet companies in 2001 - as the relevant literature half ashamedly notes - it was above all the "porn sites" that "survived the debacle unscathed" as a result of the "nature of the product - the demand for sex is the last thing to decline." "In fact, the internet economy has a lot to thank the porn industry for. Not only does the industry account for a considerable proportion of sales, it is also considered to be particularly keen to experiment. New forms of advertising often first appear on sex sites before they can be found in mainstream offerings. "[32] Of course, erotic fantasies remain eternally unsatisfied in a digital way, so they are a potentially infinite market - but they are not the only ones.

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or electronic wish fulfillment eventually turn out to be a soap bubble.

To what extent does the human play instinct open up an unlimited field for new technology? Computer games could give this impression. Among slot machine producers, however, those who were particularly successful were those who were not too quick to jump on the electronic bandwagon, but stuck to the old rattling mechanical devices that many gamblers were attached to. It also seems that the human instinct for movement prevents young people from spending all their time in front of a PC. Despite all the new technology, the most popular game that arouses the strongest emotions remains the old soccer, this ever new variation of the same thing, which - even if it has become a media spectacle - is still based entirely on physical technology. In the fitness centers, a technique of its own has developed; of course, it is entirely in the service of the modern body cult. As the human anatomy remains the same, at least in certain basic features, despite new body-shaping techniques, it also sets limits to the *citius, altius, fortius* of fitness technology.

The new perspectives on technology and the new disdain for tradition in German industry. There is much to suggest that the great age of technical innovation is a historically limited era and not a modern age that will continue indefinitely. It appears that the framework conditions for economic and technical development in recent decades have been characterized by the following main trends: Coming from the USA, the philosophy is increasingly spreading among company boards - which are pressured by powerful shareholders - that the purpose of companies is solely *"shareholder value"*, maximum profits for shareholders, not the well-being of employees - as if the long-term success of a company did not also depend on the employees' identification with the company! This philosophy is typically proclaimed in an aggressive tone; opponents are dismissed as diehards. A greed for top dividends, hardly known in Germany until recently, is rampant. The corporate tax reform implemented from 2000 onwards by the red-green government of all people - a tax relief of a kind that no CDU government had dared to implement - has increased the attractiveness of capital transactions: since 2002, shareholdings in companies may be sold without the profit having to be taxed. The philosophy that capital should flow as quickly and unhindered as possible to where the highest profits can be made is considered progressive even by ex-leftists - as a contemporary imperative of globalization and the digital revolution.

In the 1990s, Jürgen Dormann was named "Manager of the Year". celebrates: someone who "fillets" a traditional company, who takes on the current

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The company cuts out the most profitable parts, sells off the rest and ridicules all outrage from the workforce as "sentimentalism". With the aim of double-digit annual profits, sectors with mediocre, albeit solid, earnings are being sold off everywhere. However, since double-digit percentages in annual profits can never be achieved in the long term, the winners are usually major shareholders and speculators who know how to get out in time. This is a relapse into the luck and robber baron mentality of early capitalism - also recognizable in the drastically increased managerial criminality - and the opposite of the professional ethics analysed by Max Weber, which gave rise to solid, sustainable capitalism. There is a deep discrepancy between the focus on short-term maximum profits and that on long-term technical developments: presumably one of the main reasons for the ever louder calls for state technology policy.

As paradoxical as it sounds: In their demonstrative contempt for tradition, as if the break with tradition as such were proof of modernity and the future, this new generation of managers, although they have the slightest sense of socialism, seems like a counterpart to the 1968 generation of intellectuals, who - fixated on unrealistic communist utopias and at the same time on an institution-hostile cult of individual spontaneity - ignored and despised Germany's real socio-political traditions and thus mentally prepared their erosion nolens volens.[33] Analogous to the old "New Left", the protagonists of the "New Economy" think in a one-dimensional, quasi-digital dichotomy of "backward - progressive". Looking back, we can recognize qualities of the "German production regime" that intellectuals neither knew how to appreciate nor even perceived for the longest time. In the past, German industry was by no means dominated by pure traditionalism; on the contrary, German industrial history since the 19th century can be written to a large extent as a history of the appropriation of American methods: a selective appropriation modified according to German conditions. At the same time, it is clear that many entrepreneurs were not as consistently and exclusively oriented towards the return on capital as Karl Marx and his antipode Milton Friedman ("The business of business is to make money") claimed. The current situation sheds new light on history.

Today, when in business circles success is equated with the rationalization of employees, it is with incredulous amazement that one can rediscover the naturalness with which it was a matter of honour in many German companies after 1945 to re-employ former employees who returned from war and imprisonment, despite a completely uncertain future, and at the same time to keep the women who had stepped in during the war at the company.

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to keep. The fact that the human capital embodied by the workforce is decisive, even if the fixed capital invested in company assets is in ruins (and the company boss is in custody for denazification), was a fundamental experience of reconstruction. For a long time afterwards, it was still unthinkable in many companies to dismiss experienced specialists when the economy fluctuated: The experience and loyalty of the workforce were considered valuable capital - and the historian of technology, who is not overcome by the fetishism of things, can only agree with this view. Calculations about dividend percentages were not an issue at all: an attitude that makes today's modernizers shake with contempt.

Carl Duisberg, who became General Director of Bayer-Leverkusen in 1912, had the provision included in the contracts for all directors that they had to live in the immediate vicinity of the plant "in order to have their hand on the pulse of the factory day and night".[34] Old, now almost legendary times! In the 1980s, an old Opel worker recalled how an American visiting the company in 1933 burst out in disdain when he realized that a worker was celebrating his 25th anniversary with the company. "There's no such thing in America. 25 years? He gets a shot in the neck, that's all he's worth. "[35] At the time, this was a frightening example of Americanism; in the meantime, mobility has also become the highest of all values in German scenes. Even professors are more renowned for their turnover than for their research achievements. Being fully present, long experience and identification with the profession are undercut. Today, you meet top managers who no longer even identify with their company, but consider it uncool to stay with a company for more than a few years: an absolute novelty in German business history.

No longer the company patriarch who celebrates his company as a "big family" with company parties and company outings - as was the case for a long time in the
"economic miracle" era - is the model, but rather the "global player" with a nomadic lifestyle, forever travelling around according to the motto "any time - any place": this is how the former SPD federal managing director Peter Glotz characterizes him using the example of Telekom CEO Ron Sommer - full of admiration and in the style of Telekom advertising, just before the Telekom share plummeted.[36] The stock market crash has now been followed by a moral crash.[37] These deep plunges are also part of the new global fortune-hunting, all the more so as its ahistorical admirers are blind to such abysses. As Günter Ogger mocks, many German executives - whose favorite word since the 1980s has become "global player" - have become

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The world imagined that it could escape all risks through limitless mobility ("without borders" became a fashionable phrase).[38]

For a long time, people do not seem to have realized that boundlessness also meant a boundless lack of transparency: Modern information and communication technology fostered the illusion of a global overview and the idea that the *principle-agent dilemma* - that only the local agents have the decisive insight, especially in production-related issues, while pursuing their own interests - no longer exists.[39] As long as the anti-traditionalists are not at the top themselves, they tend to profile themselves as brash fighters against outdated hierarchies; but in recent times in particular, top managers have never before been able to command exorbitant salaries. While the USA was the model for teamwork in the post-war period, today it is the model for astronomical top salaries. As Harald Schumann, the analyst of the latest globalization, stated in 1999: "In Kennedy's day, America's top managers earned about 44 times as much as the average worker; today the factor is 326. "[40] These top people are much more removed from the view of the employees than the former local bosses. "Global players" who are constantly traveling around are not exactly ideal partners for trust-building teamwork on site, even if they are open to all sides. The corporate philosophy of American Fordism: "Top management is everything, the workers are interchangeable" - the contrast to the traditional German "master rule" - boosted the self-confidence of managers and legitimized top pay at American level. But it also imported American weaknesses into the Federal Republic.

The rhetoric of globalization and the consulting industry, which - originally adopted from the [USA41] and driven by the conversion of companies to IT - has recently boomed more rapidly in Germany than anywhere [else42 , has] created an atmosphere in leading business circles that is strangely detached from concrete know-how, as many consultants have no management experience and even less technical experience. Older German entrepreneurs did not see why they should let inexperienced people advise them and look at their cards; the new type of managers appreciated the consultants precisely because of their ruthlessness towards company traditions. In the past, veteran engineers used to complain at tech conferences that the less young intellectuals understood about concrete technology, the more meaningfully they talked about "technology" and *"science-based industries"*. Edzard Reuter, who, according to Ogger, understood less about cars "than any apprentice in the Daimler empire "[43] , as head of Daimler-Benz, sought to shape his company with determined ruthlessness.

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The fiasco was typical of the company's efforts to transform itself into a "technology group", which resulted in losses of at least eight billion Deutschmarks, if not much more.[44] The fiasco was typical.

In the style of popular literature, it is no use looking for the causes in the personal defects of certain managers. The destruction of the economically sound Hoechst Group by its own boss - an unprecedented grotesquerie in the entire history of German industry - cannot be explained solely by Dormann's character, but also by the fixed ideas of the time.[45] A general problem can be recognized in the background: The masses of capital seeking investment worldwide are becoming ever more gigantic, and at the same time the gap between profit expectations and average profit opportunities is growing; because the field for the really big innovations is shrinking, new needs have to be aroused with ever greater advertising expenditure; the unsatisfied needs of the vast majority of humanity, who do not have much money, are commercially uninteresting, and the needs of the saturated for a life without stress, for "wellness", for love and unspoiled nature cannot be satisfied with technical innovations, or only to a very limited extent. Fluctuating capital in search of top returns compulsively produces speculative bubbles that will burst sooner or later; and fashionable clichés about the *new economy add to* the bubble game. It seems that the increasing complexity of the global economy is weakening the ability to think in concrete terms and instead encouraging the rhetoric of fixed ideas.[46] An article in the *Financial Times Deutschland* entitled "The Great Race - The End of the Social Market Economy", which revels in globalization jargon, claims in all seriousness that "in the globalized world" there are "no more countries".[47] This means that industry can merge across national borders without hesitation. The thinking of large sections of the economic and intellectual elite in recent decades has clearly been dominated by a configuration consisting of a handful of simple dichotomies: "Away from the nation state - towards globalization; away from the *old and declining industries* - towards the *new and growing industries*; away from the material economy - towards the immaterial *new economy*." No idea that there are also

There can be "old and growing industries" - as well as "new and declining industries"; this possibility does not exist in the linear cliché of progress. Nevertheless, the irony of history can be seen in the fact that there is an albeit vague convergence with the "ecological revolution" in all of this: Even in business circles, composites with "bio" now have a good ring to them - "biotechnology", "biochemistry", "biophysics", *life science* - , and the car industry is also seeking to draw consequences from the realization that mass motorization cannot go on forever as before: so far, of course, at least in Germany, far too little in the way of industry

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new, radically energy-saving means of transportation would have been developed. Is it possible to overlook their opportunities too little? But why have they been better recognized elsewhere? Presumably, entrepreneurial failures are not only due to "rivets in pinstripes" sitting in the boardrooms, as Günter Ogger put it, but the economy has actually become more unpredictable due to the global dissolution of borders: only afterwards, when an innovation or merger has become a fiasco, is one always wiser. For the automotive industry in particular, the trends that had been emerging since the 1970s were contradictory: on the one hand, trendsetters proclaimed the *end of Fordism* and the shift to a differentiated range of more sophisticated cars, while on the other hand, after the 1973 "oil crisis", experts almost unanimously predicted the end of the automotive industry altogether - which, as we know today, was rather premature. Time and again, history reminds us of the unpredictability of the future.

The attacks on encrusted company hierarchies and an overly complacent resting on "economic miracle" laurels were certainly not without real reason, especially as the economic boom of the first post-war decades made very few demands on entrepreneurial skills in many German companies. The pendulum swing towards radical anti-traditionalism is based on annoying experiences with the law of inertia in traditional companies[48]; but thinking in overly stereotypical dichotomies of the outdated old and the promising new without a differentiating view of the diversity of the concrete - especially in the field of technology - has often led to a blanket anti-traditionalism that has repeatedly proven to be harmful, even disastrous.

All of this is hardly surprising given that a differentiated awareness of history has generally been poor in Germany to date. The megalomaniacal nationalism was followed, with a certain logic, by a counter swing of the pendulum: a generalized disdain for German traditions, even in places where people de facto benefited from them. This applies to German historical consciousness in general as well as in business and technology in particular. There is almost a paradox in the fact that German pioneers of that "German production regime", to which, according to Werner Abelshauer, German industry has owed a good part of its success for over a century, far less than the Japanese-American Francis Fukuy- ama, who praises the traditional German corporate culture for its sense of the importance of work ethic and company solidarity and in this respect recognizes "fascinating parallels" to the Japanese secrets of success: "The German economy has always been permeated by communal institutions for which there is no equivalent outside Europe. "[49]

As paradoxical as it may sound, Max Weber, who had the Protestant professional ethos, which he had in mind at home, strangely enough only in the Anglo-American world.

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nical world, understood this German tradition worse than Gustav Schmoller, the head of the historical school of German economics, whom he attacked[50], and one could even - horribile dictu - add that Albert Speer understood it better than Ludwig Erhard, who tried to drive out the "unhealthy solidarity" from German entrepreneurs after the end of Speer's "defense economy" and to educate them to no longer feel like "colleagues" but as competitors.[51] The tradition of internal employee co-determination, which spared companies many social frictions[52], was just as suspect to the liberal ecologists as it was to the radical left.

The "German production regime", more a product of practice than theory, largely operated in an ideological no-man's land between the prevailing discourses. It was least appreciated by the bulk of popular economic literature: Instead, again and again - right up to the American stock market crashes - mockery of the German lack of risk capital, of the consideration given to works councils when rationalizing away employees, of the inertia to innovate and of the leisureliness in the transition from a production to a service society.

"In the American computer industry, the daring, the willingness to gamble, the speed and the market orientation are far more uncompromising than in Europe," proclaimed Peter Glotz in an article that hardly omits any of the common global player clichés in 200353 - shortly before the weakness of the American economy became apparent. At the end of 2007, however, Der *Spiegel* mocked that the service society in the USA would not be able to "fill the gap" left by the production society. "The once proud industrialized nation has been emaciated to its skeleton. "[54]

In the conceptual triology of "primary", "secondary" and "tertiary" economic sectors - agriculture, industry and services - it has long been customary to speak of the repression of the primary by the secondary and then the secondary by the tertiary sector as if it were a law of modernity and to blame the German economy for being behind schedule in the latter process. This also leads to the conclusion that the history of technology is antiquated. Or is it the magic of the number three that suggests a law here? Only in the heights of abstraction can these three realms be clearly distinguished from one another; in the real world they merge into one another. And as soon as you think in concrete terms, the "tertiary sector" becomes a motley panorama of bureaucrats and consultants, policemen and psychiatrists, corporals and pub landlords - groups of people whose growth is not generally an indication of progress. The rise of the "tertiary sector" can be nothing other than Parkinson's law of the unstoppable growth of bureaucracy. If the

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Germany is lagging a little behind the rest of the world, but this need not necessarily be held against it. If you look at the rapid rise in many commodity prices in recent times, you even have to reckon with the possibility that not only the "secondary" but even the "primary" sector will come back into its own in the future. More reliable than all the alleged laws of history - and certainly than teleological three-phase laws - is the natural law that people must eat.

Had the German production regime really become an anachronism at the turn of the millennium? On closer inspection, "globalization", the supposed sign of the new traditionless era, was anything but new; it was a centuries-old process that had already taken on a spectacular form in the world exhibitions of the 19th century. Even then, "world" composites began to proliferate: "world traffic", "world economy",
"Global standing", "global politics" - and ultimately "world war". The German industrial profile was not only the result of domestic German traditions, but also essentially a reaction to the globalization processes of the time. It seems that even today, the path to success does not lie in imitating the Americans or Chinese, but in returning to one's own strengths. However, it seems that many "global players" have hardly any idea of these, and the majority of economic literature does little to help them.

Under the motto "Away from the car - towards an integrated technology group", Edzard Reuter, as head of Daimler-Benz, acquired the armaments and aerospace giant Messerschmidt-Bölkow-Blohm (MBB) in 1989 of all years, when all signs pointed to imminent disarmament. The "synergies" - the new magic word! - turned out to be non-existent when things got concrete, and neither did the expected spin-off of the cutting-edge armaments technology. The situation was no better with the "synergies" in the expensive purchasing at AEG and Aerospace: all areas of technology that were beyond the competence of Daimler-Benz. Reuter's successor, Jürgen E. Schrempp, tried to do better by sticking with the automotive business, but - as it was obviously not possible without a really big coup - he played the "global player" and acquired Chrysler. The discrepancy between German and American corporate culture turned this merger into a farce.

The deal concluded in November 1999 between Mannesmann and the British-American mobile communications group Vodafone was considered the "biggest takeover of all time" and at the same time the "end of the German post-war economic order "[55] , according to the motto "Away from steel - towards communications technology, away from the traditional German company - towards a global group". Mannesmann CEO Klaus Esser was intoxicated by the "vision of a European mobile communications group", but also by the ulterior motive

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After long, tough negotiations, Mannesmann was bought out by Vodafone at almost twice the price of the previous share price: the shareholders were able to rejoice - at least for the moment - and the leading management provided for themselves generously, but the workforce of the hitherto solid, traditional company faced an uncertain future. Until then, according to Klaus Zwickel, head of the IG Metall trade union and deputy chairman of the supervisory board, Mannesmann had been a "very healthy company" whose employees identified with the company. As a result of the deal, the workforce shrank from 130,000 to 30,000 and finally to 7,000: the Mannesmann telephone employees.[57] The exorbitant bonuses that Mannesmann's previous chief executives had received for giving in, on the other hand, led to the longest white-collar criminal proceedings in German post-war history, with the Federal Court of Justice declaring the lawsuit against the managers justified after almost seven years of dispute.[58]

Recently, the fate of the major German chemical companies, which had been the flagship of German science-based technology for over a century, has been particularly striking. As late as 1988, Bayer and Hoechst were still flaunting their sense of tradition in impressive presentations of the company's history, while Hoechst's in-house historian Ernst Bäumler once again described his global company as one big family - that of the "Aniliner" and "Rotfabriker" - and concluded with what he called the company's "categorical imperative": "Hoechst wants things to be human in the company." "With this sentence in their luggage, the Rotfabriker can calmly set off on their journey into the future." Wrong! A decade or two later, these companies had changed beyond recognition. From 2002, Bayer mutated into "New Bayer", not least under the pressure of the Lipobay crisis (see below): The crop protection division was merged with the corresponding division of Aventis to form a separate company and the traditional chemicals division was completely spun off from the Group under the new name "Lanxess". It was above all the workforce that mourned the loss of "mother Bayer". "Anyone who thought they were at home at Bayer now feels locked out," complained the Works Council, which reluctantly agreed to this "recently unthinkable" break-up of the company. In 2006, Bayer bought the Berlin-based company Schering, which had become famous for the "birth control pill", for almost 17 billion euros and thus made a risky attempt to integrate a very different corporate culture.[59]

The break with tradition at Hoechst was even more drastic. Jürgen Dormann, characterized by *Der Spiegel* as "Germany's most radical manager", drove the Hoechst Group, which he had headed since 1994, towards the modernization of the company.

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Dormann's radical reorientation, which was geared towards a new way of thinking, went so far that in the end there was not much left of this renowned traditional company.[60] When he tried to turn Hoechst into the world's largest "life science" group in a tour de force - another characteristic conceptual bubble of our time![61] - he left the company 16 billion Deutschmarks in debt and was ultimately forced to split up the manmade fibers division, in which Hoechst traditionally held a leading position, and sell it to the highest bidders around the world. At the time, this yielded "only" eight percent; Dormann wanted over 20 percent. However, it soon became apparent that the supposed synergy between the pharmaceuticals and agrochemicals businesses, which were to be bundled under the label "Life Science", did not exist, nor did the synergies that Reuter believed he could see from the top of the Daimler Group.[62] On January 1, 2000, Hoechst merged with the French pharmaceutical group Rhône-Poulenc; the resulting company, Aventis-Pharma, is under French management and spun off large parts of Hoechst. "Europe's first global player" had "mutated into a French global corporation", commented the *Handelsblatt in* 2004. With the contrived cheerfulness of global children at play, the "Hoechst Industrial Park" had still been underway the previous autumn under the motto "Come with us into the future" to an open day.[63] What is particularly thought-provoking about all this is that the exaggerated belief in the

The last cry of science here, as elsewhere, comes from newly appointed economists who want to multiply returns - even if only for the very near future - whatever the cost, and not from engineers and chemists who are accustomed to concrete thinking and appreciate the company's tradition of expertise. As a result, the Frankfurt district of Hoechst became a ghost town in some cases, while in the company segments that merged partly with the American group Dow and partly with the French Roussel Uclaf - according to Der *Spiegel* - the employees, who were no longer allowed to speak German, spoke "in a horrible gibberish".[64] "If you put on your national glasses, you can of course moan," Dormann told an interviewer from the magazine *Cicero*.[65] Roland Tichy, however, who as editor-in-chief of the business magazine *Euro is* not exactly suspected of nationalistic narrow-mindedness, emphasizes the negative, ex- emplary character of this debacle: "The current case of Hoechst shows: If these economic organisms have their heads cut off and their cultural roots destroyed, then they become takeover candidates for smaller competitors and innovation and competitiveness are reduced. "[66]

Leading managers in the chemical industry partly constructed the crisis that they needed as a constraint for reorganization themselves.[67] Or was it really not possible to continue the traditions that had existed up to that point?

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Forced to radically reorient itself? Recent developments at BASF, the third of the Big Three German chemical companies, suggest the opposite.[68] Long before Bayer and Hoechst, indeed since the 1960s and more intensively in the 1980s, BASF had been toying with strategies of radical reorientation, trying its hand as a German-American company and making forays into the pharmaceutical business, which had been marginal in Ludwigshafen until then, and even into information technology, the epitome of a "new" industry of the late 20th century. But BASF's top management backed down in time when the hybrid German-American corporate culture did not work, the dissatisfaction of the workforce became a noticeable negative factor and the expansion into new sectors brought neither the hoped-for profits nor synergy effects. The return to traditional production lines such as plastics or crop protection products, which the innovators had considered boring, proved to be incomparably more lucrative than venturing into new territory. At universities, students ran from traditional chemistry to biochemistry and biophysics; but if the old chemistry became scientifically uninteresting, this did not mean that it no longer brought in money.

At the end of one of the most detailed studies of German corporate history, Werner Abelshauser draws the remarkable conclusion: "In the end, BASF's corporate culture proved to be extremely resistant to the management's will to change. Its institutions were deeply rooted in the thinking and behavior of Aniline employees at all hierarchical levels and were repeatedly rewarded and reinforced by the market and politics in the 20th century." For a century, the "core of BASF's corporate culture" has been its "technological expertise", which has enabled the company to develop the Verbund system specific to the chemical industry to a higher level of perfection than its competitors. However, where this basis was abandoned, none of the hopes associated with the innovations were fulfilled.[69] Certainly, no one can predict whether *"back to the roots" will* prove to be a recipe for success in the future. History shows that there are no absolutely reliable recipes for success. But it does guard against the fashionable illusion that fundamental innovations are the path to success par excellence.

Presumably, the processes described are not only related to fashionable thought patterns, but also to fundamental difficulties in developing innovative product groups for previously unsatisfied human needs. For a long time, it looked as if the affluent society's hunger for pills was almost insatiable and that the pharmaceutical industry was the most promising sector among the big money-makers after the drug mafia.

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service providers. However, the pharmaceutical business has its own pitfalls: Success is very much dependent on a limited number of best-selling drugs; and their invention does not often succeed. Only after lengthy testing can they gain the trust of a more critical public. In 1934, the chemist Robert Wizinger described the profession of developing pharmaceutical preparations, which is a frustrating one for ambitious scientists: "On average, out of six hundred new preparations, perhaps three actually reach the market, and five-sixths of these disappear again within a short time." And he teaches that the "most important quality of a good chemist" is: "Patience!"[70] The conditions of pharmaceutical development therefore contradict a strategy geared towards short-term top profits. Aventis, which emerged from the merger of Hoechst and Rhône-Poulenc, was supposed to launch two new pharmaceutical products per year: a target that an experienced pharmaceutical expert could only laugh at.[71] Exports to the USA are particularly risky, as the product liability laws there threaten a flood of lawsuits if a drug has unexpectedly harmful side effects.

Bayer had become world-famous since 1899 for its painkiller Aspirin, which was probably the most famous drug in the world for a long time. But from 1898, the company had also launched heroin on the market as a supposedly harmless painkiller. Even Max Weber, who suffered from insomnia at all times, was at times addicted to heroin.[72] "The greatest disappointment that science has experienced bears the name heroin," wrote former BASF CEO Matthias Seefelder.[73] Fortunately for the Leverkusen-based company, the name "heroin" only became a scare word at a time when the public had forgotten the origins of this drug. Bayer, on the other hand, was plunged into a serious crisis at the turn of the millennium by the cholesterol-lowering drug Lipobay, which was launched on the market by Leverkusen and caused side effects including muscle breakdown and death. Compensation claims from American patients ran into the thousands, and the consequences were horrendous for the company's reputation and share price. It was this debacle in particular that prompted the restructuring of the company.[74]

It was not without reason that Dormann believed that famous Hoechst pharmaceutical triumphs of the past were unrepeatable: "Times are no longer as they were at the end of the 19th century, when Hoechst conquered the world market with the influenza drug 'Antipyrin'." (*Handelsblatt*)[75] Although there are still *plenty of* unfulfilled drug desires among mankind, it must be expected that many of these desires will remain unfulfilled. The ideal sleeping pill, painkiller, tranquillizer and antidepressant that works reliably and has neither unpleasant side effects nor is addictive still does not exist after a hundred years of searching. The same applies to many other miracle

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drugs that stressed-out humanity craves. The Swiss pharmaceutical company Hoffmann-La Roche had recognized vitamin supplements early on as the new boom products of an era obsessed with natural remedies and launched them on the market; BASF gave up trying to compete with the Swiss company in this field.[76] However, most areas of natural medicine, which expanded rapidly in the eco-era, offered few opportunities for monopoly profits based on high-tech.

High-tech, greentech, cleantech. And yet: *"Greentech is generally high-tech"*, proclaims an *environmental technology atlas for Germany* published by the Federal Ministry for the Environment.[77] In computer technology, there is no talk of "German technology"; quite the opposite in environmental technology: hardly anywhere else is "*Made in Germany*" proclaimed as proudly and resoundingly as here! While the "dual system" of vocational training, once a German specialty[78] , is only known to a few people today, a new system has been under development since the 1990s.

"Dual System Germany" proclaimed: a system of waste recycling. "The role of German biogas producers is particularly dominant, holding around two thirds of the global market "[79]: a position comparable only to the global position of German potash and paint chemistry a hundred years ago! Not only the Federal Ministry for the Environment, but also the investment information of Deutsche Bank announced in 2008 - referring to environmental technology not as *greentech*, but as *cleantech*: "Environmental technology will be Germany's No. 1 growth sector." Is this also a speculative bubble of the capital masses looking for new investment objects, especially as the leading position of German environmental technology depends decisively on political guidelines? There is not much mention of the global market here: "In all lead markets, the domestic market is very important for companies in Germany. It is by far the most important sales market. "[80] And yet there are great export hopes, because the trend towards environmentally friendly technology is global and is not only stimulated by government regulations, but also by consumer behavior. To the surprise of inveterate cynics, "certification" - the documented guarantee of a certain ethical and ecological correctness of products and the way they are manufactured - has developed into a flourishing industry of its own since the 1990s.

Environmental technology" is not a sector like coal, steel, chemicals or mechanical engineering, but a heterogeneous bundle of different areas of technology that is essentially held together by government environmental policy. This includes renewable energies, technologies to improve energy and material efficiency, waste recycling, thermal insulation processes and lower-emission and fuel-saving transportation technologies. The various sectors are dominated by very different types of companies. One

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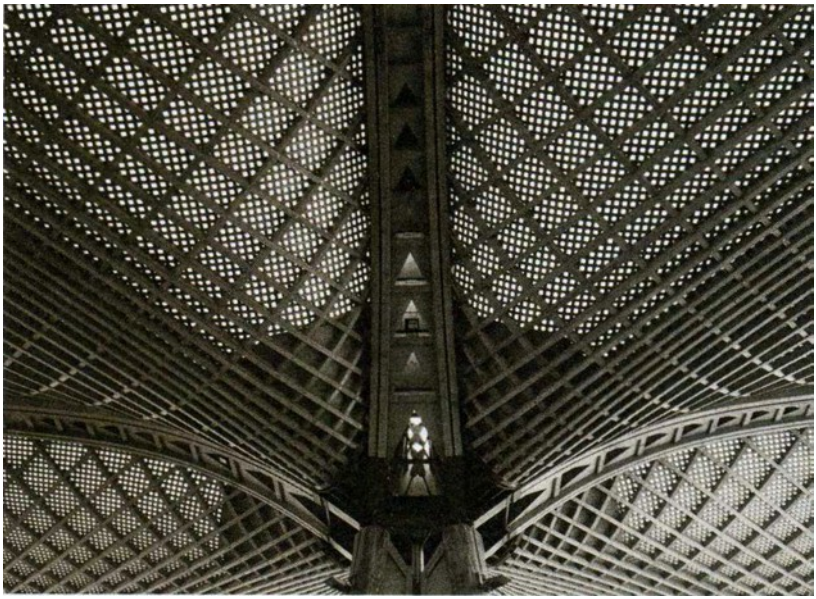

Figure 44*:* The giant wooden roof at Expo 2000 in Hanover, which was held under the motto: "Man, nature and technology - a new world is emerging". For this largest wooden roof in the world at the time - 160 by 120 meters wide - 5,300 solid cubic meters of wood were used. It was intended to demonstrate the untapped potential of wood as a building and construction material. After wood had long been discredited by "modern" construction engineers due to its unpredictability and perishability, timber construction experienced a renaissance thanks to modern gluing techniques, especially at a time when people had already had sobering experiences with the rapid perishability of concrete buildings and natural materials were booming in the name of the "environment". Thanks to its tensile strength and comparative lightness, timber is suitable for bridging extreme spans. The extent to which the technical advantages of wood are utilized today is essentially a question of building standards.

technical synergy is very limited. Environmental policy cannot rely on the dynamics inherent in environmental technology.

In his "History of High-Speed Traffic", Lutz Engelskirchen creates a panorama of the technical and supra-technical synergies of recent times: "The breakthrough of computerization, the (new) media, digital technology and the associated enormous acceleration of communication [...], the final dissolution of traditional small-scale social milieus, the international interweaving of business and politics [...] ran and run parallel to the history of technology. "[81] Environmental technology is in no small part a by-product of this bundle of synergies82; in part, however, these synergies also miss the mark in terms of environmental protection. Especially in the eco-era since 1970, air traffic has grown explosively; the

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The long overdue taxation of aircraft fuel is taboo even in large parts of the long-distance eco-scene. The "paperless office" was one of those false predictions associated with computers that seems particularly ridiculous today given the immensity of computer printouts[83] - or are these merely relics of the paper age? The growing pace at which computers are being scrapped is creating new kinds of disposal problems.

Privatization of technology - individualization of work. Another by-product of the digital era is the elimination of many old occupational health and safety problems that arose from manual contact with machines and materials. The growing speed of industrial technology, the stronger forces at work and the clouds of dust generated dramatically exacerbated the risks of work in many sectors until the 1970s: VDU workstations created a completely new situation, even if - as is often overlooked - not in all areas of work. While the "humanization of work" was a major topic in the 1970s and 80s, today it is almost forgotten even in trade union circles. Humanization" included precautions against the increasing compression of working hours; however, these efforts were undermined by the screens, which made it possible to work without breaks and at the same time to control work without breaks, and even encouraged this. The new type of psychosomatic stress caused by screens is far more unclear and confusing than the traditional work risks were. In a time of increasing individualization of work, it is primarily experienced as an individual problem.[84] At times, trade unionists tried to push through general break regulations for VDU workers in the name of "humanization"; however, they met with opposition even from many employees who did not want to be talked into their daily routine. Ergonomics, whose rise dates back to the early days of Taylorism and Fordism, fell silent at the sight of the new complexity of the digitalized world of work.[85]

Even the rationalization protection agreements first devised by IG-Metall in 1968, on which the trade unions pinned their hopes a generation ago, are now among the almost forgotten issues of yesterday. In March 1978, IG Druck und Papier was still on strike when computers were rapidly making typesetters obsolete and forcing these members of a previously very self-confident profession into lower-skilled and lower-paid employment. At the time, a typesetting computer could do a hundred times as much as a conventional lead typesetting machine. It was here in particular that the "electronic revolution" became a socio-political event.[86] The strike against a technical innovation was and remained a uni

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Figure 45: Typesetter at the Linotype typesetting machine in a newspaper printing plant (1942). Typesetters were the intellectuals among the workers: they had to understand the texts they were typesetting in order to avoid orthographic errors, and they took pride in this ability. Typesetters were one of the most self-confident professions in Germany; they were the only group of employees who tried to defend themselves against the introduction of IT, which largely devalued their traditional qualifications, by going on strike. Around 1900, they were already one of the rare groups of workers who raised the issue of the increased work stress caused by the modern pace of work, but also the traditional health risk of printers: lead poisoning, the most common occupational disease of all until the 20th century.

and could easily be ridiculed as "machine storming" - the standard accusation against any criticism of technology! - to the point of ridicule. However, the trade unions' demands were not aimed at a ban on innovation, but merely at social security, and this was achieved - for existing employees, not for future employees.

The "Collective agreement on the introduction and use of computer-controlled text systems", a novelty in terms of collective bargaining policy, was to become a model for future ratiocination protection agreements; from today's perspective, it has remained an episode. Later, the legend circulated that it was thanks to EDP that typesetters were finally no longer threatened by lead poisoning, their centuries-old occupational disease. However, this danger had already been largely eliminated in this profession - not in others - around 1900 through hygienic measures. Generally speaking, the de-skilling of work as a result of the "digital revolution" that had been a major threat

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at the time of the printers' strike did not occur.

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was feared; instead, new forms of skilled work have emerged. However, it is easy to overlook the fact that hard and dull work still exists en masse in these new worlds of work that are attracting interest. At Bayer in the 1980s, rationalization protection in the wake of advancing EDP became the subject of the front of the "transparent" against the established works councils. In 1989, an IG-Chemie information leaflet ridiculed a spokeswoman for the "transparent ones" with a caricature depicting her as a "figure almost mutated into a pig" screaming out "hazardous substances, shift work, IT systems". Along with the verse: "So you hear her screeching everywhere, she thinks it's Pablick Rileischn!" The rebels articulated fears of the "base" that would normally remain unarticulated. "Unspeakable fears shut the mouths and outlooks of many of those affected by organized microelectronics," observed a *Spiegel* journalist in 1982.[87]

From criticism to positive criteria. A number of prominent borderline cases deserve special attention, where it is hotly disputed whether they belong to the

"environmental technology" or not. Is biofuel the environmental technology par excellence or - as a monoculture of "energy crops" - more of an ecological horror? Is hydrogen produced by solar energy the definitive sustainable patent solution to the fuel problem when fossil fuels are used up or are no longer viable for climate protection reasons, and when biofuels compete with feeding humanity in a socially intolerable way? Or is this a far too expensive dead end, originating from the military-industrial complex, which distracts us from simpler forms of solar energy utilization? What about hydroelectric power plants and wind farms in the sea? What about the magnetic levitation train that once carried the inhabitants of Callenbach's "Ecotopia" and recently failed in Munich? How about the project to operate huge oil tankers with gigantic sails? Wind energy for oil transportation of all things?

One of the most adventurous and now forgotten projects was the "Cargolifter": a super zeppelin 260 meters long that was to transport heavy loads of up to 160 tons; Cargolifter AG, founded in 1996, filed for bankruptcy in 2002, leaving behind a 360-meter-long and 200-meter-wide hangar south of Berlin that would provide space for 14 jumbo jets.[88] This grotesque is also a spawn of one-sided energy and emission-saving thinking that ignores other important aspects - a memento at a time when climate protection threatens to overwhelm all other environmental concerns. The saying about the "devil in the detail" applies - how could it be otherwise? - also applies to potential environmental technologies.

By far the most famous and controversial example are the techniques for manipulating biological processes, which go by the name of "biotechnology".

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The German biotechnology movement was fiercely attacked by the environmental movement under the name of "genetic engineering". "In the shadow of chemical synthesis", biotechnology in Germany - as Luitgard Marschall has shown89 - had remained a "niche technology" for over 70 years - although a "niche" like beer brewing was still spacious; now it was beginning to become "mainstream". The extent to which genetic engineering using new DNA combinations can be clearly distinguished from other types of manipulation of biological processes in terms of its risks remains unclear to this day. And the opportunities and risks of the very latest "cross-sectional technology" - nanotechnology - are even less clear.

Here, as earlier in history, imitation of nature and manipulation of nature are not contrasting worlds separated by a deep gulf, but are often confusingly similar. The future of the environmental movement is likely to depend very much on the extent to which it develops criteria not only for the rejection but also for the acceptance and promotion of techniques. There has been significant progress in this respect in recent times, but there are still many unanswered questions. Only to the extent that environmental protection attracts not only critics and obstructionists, but also people of action, not least technicians, and creates coalitions of actors around it, will it gain the power to play a constructive role in shaping the course of events. Dichotomous thinking in terms of "good - bad", as if this were a foregone conclusion, is often misleading; here, as elsewhere, it is more a question of learning processes, and that also means the ability to retract previous positions.

The "Ingenieurlied" from 1871, to be sung to the tune of "Krambambuli" and written by Heinrich Seidel, the builder of the Anhalter Bahnhof and author of the cozy idyll *Leberecht Hühnchen*, begins with the verse:
"Nothing is too difficult for the engineer, he laughs and says: 'If this doesn't work, that will!' He bridges the rivers and the seas, it's fun for him to pierce the mountains without freezing. He piles the arches in the air, he digs as a mole in the grave, no obstacle is too big for him, he goes for it!" The first thing that catches the nature lover's eye is the ambition to dominate nature; but he should also see other sides to this engineering joy: the playful pleasure - far removed from a narrow profit calculation -, the confidence that problems can somehow be overcome, and thinking in alternatives:
"If this doesn't work, that will!" Engineers were not always and everywhere committed to fixed "technology paths", but also this other one: curious experimentation with imagination for alternative solutions is part of the engineer's original drive. And this is precisely what is needed to make technology more human and environmentally friendly.

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Figure 46: "Icarus", by Bernhard Heisig: Painting for the 1975 inaugurated "Palace of the Republic" in the GDR. The crashed aviator from Greek mythology is one of the favorite themes of the painter, who was born in 1925 (as was the songwriter Wolf Biermann). The picture is strangely ambiguous: in the past, it was recognized as a socialist Icarus who manages to stay in the air during his solar flight (or Sputnik flight?); nowadays, however, he is more associated with Christ on the cross, which Heisig also painted several times. "Icarus is frozen in the sky while flying, as it were. The dying Icarus can no longer crash" (Peter Pachnicke). There was a second Icarus in the paintings in the Palace of the Republic: in the politically correct painting by Walter Womacka: "When Communists Dream". Here, the falling Icarus symbolizes capitalism, doomed to destruction!

In 1992, Ulrich Steger, then Chief Environmental Officer at VW, complained to interviewers from Die *Zeit* that the "biggest problem" of long-term investment planning was that "we have no model for our transport system in 2010. I say this with great regret, above all because it makes business incredibly difficult for the industry."[90] Now, the car industry is certainly not innocent of the fact that, despite all the commitments to "sustainability" in German politics, there is still no binding model for a transport system that takes "sustainability" seriously. The fixed idea, still propagated by the automobile lobby, that the German recipe for success is the high breeding of engines, reveals a high degree of historical ignorance. It is all the more strange that this argument still holds water. There has long been a political stalemate between the environmental movement and the automotive industry. Even in the name of ecology, no federal government has dared to seriously take on the car lobby.

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Is the global trend heading towards the "eco-car"; will this be the patent solution in this conflict? Carried up by the climate alarm and steeply rising oil prices, it has already achieved discourse dominance. But are the discourses of today the reality of tomorrow? There is still a lot to suggest that the ecomobile is a chimera that distracts from the need for a radical change in transportation: towards intelligent combinations of public transport and bicycles. As automotive historian Kurt Möser shows, many supposed advances towards the "eco-car" have so far proved to be a sham. "Most of the technical tricks used to make engines more economical can just as easily be used to increase performance",[91] which is what usually happens: an ambivalence of "saving" that is already familiar from the era of wood-saving projects. And just like a hundred years ago, the battery problem still weighs like lead on the prospects of the electric car, despite recent progress. Moreover, it is still highly questionable whether it is rightly being touted as an "eco-car".

A politically enforceable model in the foreseeable future could, however, not be a consistent "bicycleization" of traffic, but only a philosophically unsatisfactory compromise; but that would still be better than letting traffic development run unchecked, which makes a mockery of all environmental commitments. Thinking about environmentally compatible technology strategies for the future will have to concentrate on enforceable concepts - there have been enough big words. "Environmental technology" requires technical imagination, but always includes a mandate for political thinking.

In the Greek myth, Daedalus spoke to his son Ikaros when he had made a large and a small pair of wings for himself and him: "Always fly at a medium height, so that if you lower your flight too much, your wings do not touch the sea water and drag you down into the depths of the waves, weighed down by moisture, or if you climb too high into the air, your feathers come too close to the sun and suddenly catch fire." An admonition to take the middle path, entirely in the spirit of classical Hellenic and Buddhist wisdom. Ikaros has become more famous in the history of art and literature than Daedalus. But the wisdom of Daedalus is not a bad mythical model for dealing with modern technology. As you can see: The basic problems are ancient. Successful innovation requires caution and experience. Those who carefully stay in the middle stay on top, make progress and survive.

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Notes

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Initially on a particularly radical protest course, but later succumbed to the monumental fascination of the large dam wall. (note from Frieder Schmidt)

IV. Wartime, pre-war and post-war times: The rationality of mass production, power and hardship

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the reports of Opel workers collected by Schirmbeck, which focus on the period from the 1930s to the 1950s, much more job satisfaction is reported.

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than in the statements published by Levenstein in 1912, without this being the intention of the interviewer. The impression is confirmed by Pot, I, 451f. In Popitz et al, Das Gesellschaftsbild des Arbeiters, Tübingen 19724, 45, 48, 55f., which is based on studies in the iron and steel industry in 1953/54, there is the revealing o b s e r v a t i o n t h a t although the specific technical innovations of the time were generally appreciated as making work easier, overall a critical-pessimistic assessment of "technical progress" prevailed! The experiences of the wars and the global economic crisis were obviously incorporated into the general statement. In the Marxist tradition, it would have been logical to take a critical view of specific innovations and a positive view of general technical progress.

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Im Banne der Ätherwellen, II, Stuttgart 1956, 49f.; Ehrhardt, 79, 85, 82, 107; F.Dessauer, Philosophie der Technik, Bonn 1927, 15f.; B. von Bülow, Denkwürdigkeiten, Bd. 2, Berlin 1930, 227f.

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69 Plumpe, 319ff., 337ff., 342ff., 535; Holdermann, 210ff.

70 R. Bauer, Das Jahrhundert der Chemiefasern, Munich 1951, 118f., 216; Bäumler, 193.

71 K. A. v. Müller on O. von Miller: "like an old, indomitable protective spirit of the homeland" (Kristl, 189); Pinner, 160f.

72 Weingart, Strukturen, 125f.; Ludwig, Technik u. Ingenieure, 54; Hilferding: M.Dierkes, in: ders. u.a., Technik u. Parlament, Berlin 1986, 130.

73 Holdermann, 173, 74ff; Winschuh, 93ff; L. Marschall, Im Schatten der chemischen Synthese. Industrielle Biotechnologie in Deutschland (1900-1970), Frankfurt/M. 2000, 153; K. H. Spitzky, Die Geschichte des ersten säurestabilen Oralpenicillins (Penicillin V), in: Antibiotika Monitor 3/2000.

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and at the same time science and technical progress are constantly p r o d u c i n g new alternatives" (Pot, I, 331). F. Münzinger, Ingenieure, Berlin [19422], 130, already ridiculed the belief that there was "a certain unambiguous answer" to all technical questions as a typical misconception of limited "mathematical engineers" who only understood technology as the application o f certain theories.

75 H. Hinnenthal, Die deutsche Rationalisierungsbewegung u. das Reichskuratorium für Wirtschaftlichkeit, Berlin 1927, 8f., 11, 25; Heuss, Bosch, 423; J. Radkau, Renovation des Imperialismus im Zeichen der "Rationalisierung", in: ders. u. I. Geiss (eds.), Imperialismus im 20. Jahrhundert, Munich 1976, 219f.

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A. Wulf, "Maschinenstürmer sind wir keine". Technischer Fortschritt u. sozialdemokratische Arbeiterbewegung, Frankfurt/M. 1987, 123ff., 127ff.; O. Moog, Over there is America... Ge- danken nach einer Ingenieurreise durch die Vereinigten Staaten, Braunschweig [19273], 85, 118; Verachtung der Sachverständigen: H. Ford; Mein Leben u. Werk, Leipzig (1923), 33; L. Betz, Das Volksauto, Rettung oder Untergang der deutschen Automobilindustrie? Stuttgart 1931, 93, 94; Automobilia, Berlin 1928, 124; C. S. Maier, Between Taylorism and Tech-noc- racy, in: Journal of Contemporary History 5.1970, 54.

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L. Scarpa, Abschreibungsmythos Alexanderplatz, in: J. Boberg et al, Die Metropole. Industriekultur in Berlin im 20. Jh., Munich 1986, 126f.

79 Heuss, 413; 50 Jahre Bosch, 214f.; H.Homburg, Anfänge des Taylorsystems in Deutschland vor dem Ersten Weltkrieg, in: GG 4.1978, 180ff.; Stollberg, 83; England: Pollard, Development, 104; France: P. Fridenson, Unternehmenspolitik, Rationalisierung u. Arbeiterschaft: französische Erfahrungen im internationalen Vergleich, in: N. Hörn u. J. Kocka (eds.), Recht u. Entwicklung der Großunternehmen im 19. u. frühen 20. Jahrhundert, Göttingen 1979, 444.

80 Brady, 21ff., 27, 153; Bolenz, Normung, 6, 18, 20; Tarnow, 26; Garbotz, 50, 57ff.; H. Ford, Das große Heute und das größere Morgen, Leipzig 1926, 98; cf. Rathenau's accentuation of standardization and typification in: ders., Wirtschaft, 44 ("Würde" versus "Faschingsfreiheiten");
G. Schlesinger characterized himself as a "standards fanatic" (Loewe 119). F. Münzinger, Dampfkesselwesen in den Vereinigten Staaten, Berlin 1925, 35: "the habituation to standardized and unified parts is ultimately nothing other than a sign of d i s c i p l i n e ". On the problem of the "standardized locomotive" created in 1925, which represented a synthesis of Prussian and American designs, but which "exaggerated certain principles to excess": Born u. Düring, 32, 39. F. Ledermann, Fehlrationalisierung - der Irrweg der deutschen Automobilindustrie seit der Stabilisierung der Mark, Stuttgart 1933, 67; Pro-

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duktivkräfte, III, 91; on resistance, see also note 46. "Weltbühne" 1926/I, 808.

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81 Kocka, Unternehmer, 110ff.; Söllheim, 148; Schmiede u. Schudlich, 187; Schlesinger, in: Loewe, 134, on early negative experiences with the American premium system; G. Prachtl, Von der Reihenfertigung zur Fließarbeit, Berlin 1926, 1; Winschuh, 36; Kugler, 313f.

82 Hinrichs and Peter, 264, 99f.; F. Mäckbach, in: ders. and O. Kienzle (eds.), Fließarbeit, Berlin 1926, 6: "Fließarbeit is a result of the scientific penetration of the company, in which we Germans have been in the front ranks for decades [...]". H. Homburg, Le taylorisme et la rationalisation de l'organisation du travail en Allemagne, in: Le taylorisme, Paris 1984, 107; Tarnow, 18f.; M. J. Bonn: IHK Berlin (ed.), Die Bedeutung der Rationalisierung für das deutsche Wirtschaftsleben, Berlin 1928, 13, 26; Schmiede u. Schud- lich, 279f.; Treue, Feuer, I, 71f.; Flechtner, 189ff.

83 Hinrichs and Peter, 99f., 166 (Gottl-Ottlilienfeld); Wulf, 90, 139, 147f.; Stollberg, 90; Viefhaus, in: Ludwig, Technik, 333; Wegeleben, 10; Switzerland: R. Jaun, Mangement u. Arbeiterschaft. Verwissenschaftlichung, Amerikanisierung u. Rationalisierung der Arbeitsverhältnisse in der Schweiz 1873-1959, Zurich 1987, 205, 333ff.; Preller, Sozialpolitik, 127; similarly Aeroboe,
Overview, 121; Radkau, Renovation, 240.

84 Pellicelli, in: Cipolla (ed.), V (1), 190; Heuss, 224; G. Langheinrich, in: E. Krause (ed.), Der Industriemeister, Hamburg 1954, 99f., 163; K. W. Henning, Betriebswirtschaftslehre der- dustriellen Fertigung, Braunschweig 1946, 107; R. Dombois, in: Doleschal u. ders., 142f.

85 Schmiede and Schudlich, 283; Stolle, 191ff., 194ff., 202f.; R. Bosch 1925 at the VDI Annual General Meeting (Zs. des VDI 69.1925, 893): The widespread impression that mass and flow production in the Ford sense existed at Bosch was not correct - a fact apparently maintained by Bosch. RKW (ed.), Handbuch der Rationalisierung, Berlin [19323], 354.

86 Kugler, 332; this, Die Umstellung auf Massenproduktion in Rüsselsheim, in: TG 56.1989; R. Flik, Automobilindustrie und Motorisierung in Deutschland bis 1939, in: R. Boch (ed.), Geschichte und Zukunft der deutschen Automobilindustrie, Stuttgart 2001, 84; K. H. Roth, in: Hamburger Stiftung (ed.), 73ff.; M. Barthel u. G. Lingnau, 100 Jahre Daimler-Benz. Die Technik, Mainz 1986, 93, 95f.; M. Kruk and G. Lingnau, 100 Jahre Daimler-Benz. Das Unternehmen, Mainz 1986, 87f., 108f., 128f.; F. Blaich, Die "Fehlrationalisierung" in der deutschen Automobilindustrie, in: Tradition 18.1973, 32; VDI-Zs. 86.1942, 647; F. Klemm, Die Hauptprobleme der Entwicklung der deutschen Automobilindustrie in der Nachkriegszeit, Diss. Marburg 1929, 46; Hammer, Morphologie, 20; Kern and Schumann, Ende, 40; Schirmbeck, 58, 104: As late as the 1970s, only one fifth of the workers in the European car industry were employed on average on the assembly line.

87 Kugler, 323f, 316; Garbotz, 217 ("Woe to the people who hereby go beyond their living conditions!"); F. Meyenberg, Rationalisierung der technischen Betriebsorganisation, in: Harms (ed.), I, 223; H. Kluge, Kraftwagen u. Kraftwagenverkehr, Karlsruhe 1928, 23ff.; Morus (L. Lewinsohn), Auto-Suggestion, in: Weltbühne 1925/1, 862f.; W Hegemann, Weltretter oder -verderber Henry Ford, in: ibid, 1932/2, 207ff.; H. Ford, Und trotzdem vorwärts, L e i p z i g 1930, 133ff., 171; U. Sinclair, Am Fließband (1937), Reinbek 1987, 144f. In the patholo- gic tirade of hatred by the Taylor supporter Gustav Winter against the "false messiah Henry Ford", who is insulted as "Satanas", a conservative, middle-class c o n s c i o u s n e s s shines through. Winter, Der falsche Messias Henry Ford, Leipzig 1924, 6, 45.

88 Prachtl, 46; Mäckbach, 249; Schmiede and Schudlich, 40; E. Teschner, Lohnpolitik im Betrieb, Frankfurt/M. 1977, 67, 77f.

89 DMV (ed.), Die Rationalisierung in der Metallindustrie, Berlin (1933), 198f.; Stolle, 205; Heuss, 231; A. Hamann, Der Einfluß der Rationalisierung auf die arbeitenden Frauen, in: Urania 3.1926/27,48; in 1908, the Prussian trade inspectorate in Bielefeld had ordered the mechanical drive in lingerie factories with more than 20 employees, as "the pedalling of the sewing machine is not good for the female organism". The Bielefeld Chamber of Commerce had objected, not without good reason, that mechanized operation "puts a great deal of

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strain and strain on the nervous system of female workers". G. Ketter-

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mann, Kleine Geschichte der Bielefelder Wirtschaft, Bielefeld 1985, 98f. Nervousness: DMV, ibid., 166f.; H. de Man, Der Kampf um die Arbeitsfreude, Jena 1927, 246; H. Oczeret, Die Nervosität als Problem des modernen Menschen, Zurich 1918, 22ff.

90 RKW 322, 361 (extraordinary adaptability of flow work surprising even for the specialist); Meyenberg, 239; E. Sachsenberg, in: Mäckbach, 242; P. Warlimont, Die fließende Fertigung als wirtschaftliche Frage, in: Technik u. Wirtschaft 19.1926, 79ff.; Schulz- Mehrin, Rationalisierung u. Kapitalbedarf unter besonderer Berücksichtigung der Fließarbeit, in: ibid., 265ff.; Prachtl, 94.

91 DMV, Rationalisierung, 161; Betz, Volksauto, 30f.; F. Reuter, Das RKW u. seine Arbeiten, in: Deutsche Technik 3.1935, 323; Schmalenbach: cited in A. Sohn-Rethel, Ökonomie u. Klassen- struktur des deutschen Faschismus, Frankfurt/M. 1973, 43 f.; R. Krull, Die Bielefelder Fahr- rad- und Nähmaschinenindustrie während der Weltwirtschaftskrise, in: 75. Jahresbericht des Histor. Verein der Gft. Ravensburg, 1984/85, 192f. and 212. The bicycle company Göricke, which introduced assembly line work particularly consistently within the Bielefeld metal industry, quintupled its production as a result and already presented itself as a pioneer on the huge Asian market in its advertising, experienced the most sensational bankruptcy in Bielefeld's industrial history to date in 1929, even before the onset of the global economic crisis.

92 Ford, Leben, 133; H.-P. Rosellen, Und trotzdem vorwärts. Ford in Deutschland 1903-19435, Frankfurt/M. 1986, 32; W. Chestnut, Psychotechnik, in: Proceedings of the 80th Annual Con- vention of the American Psychological Association, 1972, 781f.; Hinrichs and Peter, 41f., 46, 60;
G. Spur and H. Grage, 75 Years of the Institute for Machine Tools, in: Rürup, Wissenschaft, 112; for the provocative word "technology", see Riedler, Die neue Technik. U. Geuter, Die Professionalisierung der deutschen Psychologie im Nationalsozialismus, Frankfurt/M. 1988, 88ff., 225.

93 P. C. Bäumer, Das Deutsche Institut für Technische Arbeitsschulung (Dinta), Munich 1930, 102ff.; Campbell, Joy in Work, 252ff.; Radkau, Renovation, 226ff.

94 The "joy of work" was also one of the main themes of the Deutscher Werkbund, although it was often associated with the romanticism of craftsmanship and scepticism towards mechanization: Campbell, 196ff. DMV, Rationalisierung, 169ff.; Kugler, 337; Mooser, Arbeiterleben, 58f.

95 G. Schwarz, Kohlenpott 1931 (1931), Essen 1986, 115. Joan Campbell (27. 3. 2008) in response to the author's question as to what extent the "joy of work" was actually felt by the workers or was it rather a euphemism of ideologues: "I do be- lieve that the German skilled workers experienced something like Arbeitsfreude, but I have no evidence that many ordinary laborers, especially after the introduction of assembly line production the 1920s, thought of work as anything more than a way of earning a living. And it was just these people that the ideologues in whom I was interested were trying to address. [...] I believe the Arbeitsfreude people I studied were generally sincere in their efforts to humanize work."

96 Putsch, 245, 249f., 258; Ziegler already claimed in 1910 that the Remscheid small iron industry was forced into large-scale production (Ziegler, 79f.); in the Solingen scissors grinding shop, on the other hand, manual work was only devalued by mechanization in the 1960s (Scherenschleiferei Leverkus, 47ff.). "Misrationalization" due to a lack of consistency in r a t i o n a l i z a t i o n : Ledermann; Hinrichs and Peter, 47 (Naphtal); D. Bauer, Rationalisierung - Fehlratio- nalisierung, Vienna 1931; E. Reger, Die Schuldfrage der Rationalisierung, in: Die Weltbühne 1932/1, 407ff.; E. Lederer, Technischer Fortschritt u. Arbeitslosigkeit, Frankfurt/M. 1981 (originally 1938), 288. De Man: Campbell, Joy, p. 178ff.

97 Sohn-Rethel, 48; Rathenau, Wirtschaft, 36; Maier, Taylorism.

98 Taylor, XIX, Seubert, 1; Riedler, Rathenau, 146; Ostwald, Lebenslinien, II, 160; Forde- rung 67; Brennstoff-Wärme-Kraft (BWK) 1.1949, 87. In 1909, Max Weber (422) described the energetic doctrine of Ostwald and his followers as a "theoretical gimmick". O. Dascher,

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Probleme der Konzernorganisation, in: Mommsen/Petzina/Weisbrod, Industrielles System, 127 fn.

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99 Kohlennot: F. Fischer, Die Brennstoffe Deutschlands u. der übrigen Länder u. die Kohlennot, Braunschweig 1901, 44f.; O. Bauer: Hinrichs u. Peter, 236; E. Kraemer, Was ist Technokratie? Berlin 1933, 30; Matschoß, Maschinenfabrik Nürnberg, 287f.; Pierson, Borsig, 193; Riedler, ibid., 84, 86; Bolenz, Normung, 16; E. von Beckerath, Neudeutsche Kanalpolitik, in: Harms, II, 210. M. Kersten, Grenzen der Energieverschwendung, in: K. Steinbuch, Diese verdammte Technik, Munich 1980, 107.

100 Archiv für Wärmewirtschaft (= AfW) 5.1924, 123, 229; ibid., 2.1921, 109; R.Stahlschmidt, in: Ludwig, Technik, 379f.; Treue, Feuer, I, 220f.; W Rathenau, Schriften u. Reden, H. W. Richter (ed.), Frankfurt/M. 1964, 412.

101 AfW 6.1925, 324f.; ibid., 5.1924, 123; G.Dehne, Deutschlands Großkraftversorgung, Berlin 1928, 14.

102 Radkau u. Schäfer, 186ff.; ders., Entscheidungsprozesse, 64f. K. Pritzkoleit, Männer, Mächte, Monopole, Düsseldorf 1953, 271.

103 BWK 1.1949, 87; ibid., 2.1950, 104, 87; AfW 5.1924, 124, 21: "The operating engineer usually thinks far too little of the ongoing operational management, of the daily management of thermal energy when he hears the word heat economy. Daily and hourly prudence in the handling of thermal energy always brings profit, especially when the thermal equipment of the plant is poor." (F. zur Nedden) AfW 6.1925, 125; on the specifically German way of high-pressure steam generation K.Heinrich, in: Zs. des VDI 91.1949, 533ff. H. D. Hellige, Conditions of origin and long-term effects on energy technology of the Energy Industry Act of 1935, in: TG 53.1986, 141.

104 Radkau, Umweltfragen, 92; AfW 5.1924, 125; ibid., 4.1923, 219; BWK 2.1950, 33ff.; F. Spie- gelberg, Reinhaltung der Luft im Wandel der Zeit, Düsseldorf 1984, 85.

105 W. I. Lenin, Werke, 19, Berlin 1962, 42; H. Hesedenz, Kohleumwandlung - eine Sackgasse? in: H. Hatzfeld (ed.), Kohle, Konzepte einer umweltfreundlichen Nutzung, Frankfurt/M. 1982, 109ff.

106 R. Sonnemann, Energiebedarfsdeckung durch thermische Energieumwandlung, in: Energie in der Geschichte, 316; BWK 2.1950, 154; Mock, 152f.; Todd, 280ff.; AfW 5.1924, 227, 22; H. D. Hellige, Die gesellschaftlichen u. historischen Grundlagen der Technikgestaltung als Gegenstand der Ingenieurausbildung, in: TG 51.1984, 286. Ostwald, Forderung, 30; Archiv für Wärmewirtschaft 5/1924, 22.

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109 Flechtner, 341; L. Graf Schwerin von Krosigk, Die große Zeit des Feuers, II, Tübingen 1958, 579, 584; W. Fischer, Dezentralisation oder Zentralisation - kollegiale oder autoritäre Führung? Die Auseinandersetzung um die Leitungsstruktur des IG Farbenkonzerns, in: Hörn u. Kocka (eds.), 476ff.; H. G. Grimm, Organisation der Forschung in der chemischen Industrie, in: Deutsche Technik 3.1935, 237; Winnacker, 73 (even within Farbwerke Hoechst there was a "colourful departmental federalism" in research around 1933). Pinner 322, 133f.; Kristl, 74ff.; W. Fellenberg, Die Entwicklung der Starkstromtechnik in Deutschland u. in den Vereinigten Staaten von Nordamerika, in: Elektrotechn. Zs. 30.1909, 1236; Wilke, 218ff.

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116 Marguerre, 5f.; Boll, 102f.; BWK 2.1950, 194, 197; W.Treue, in: Pohl (ed.), Wirtschaftswachstum, 225f.; Seidler, 290f.; J. Radkau, Aufstieg u. Krise der deutschen Atomwirtschaft, Reinbek 1983, 88.

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Bielefeld 1983, 36 (DKW), 6, 11, 39, 77, 89, 102; U. Kubisch, Motorrollermobil, Vom zivilsierten Zweirad zum Fast-Automobil, Berlin 1985, 13.

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128 Hamburger Stiftung (ed.), 84 (K. H. Roth); P. Voswinckel, Arzt u. Auto, Münster 1981. Before 1933 there was a Pastors' Motorists' Association and a Motorists' Association of German Teachers (HUK Hausmitteilungen 1983, 4f.). Klemm, 51; Bade, 341; Winschuh, 123 (Todt: "The acquisition of the motor car satisfies a deeper urge than t h e material need for transportation."); J. Linser, Unser Auto - eine geplante Fehlkonstruktion, Frankfurt/M. 1978, 23f.: The automatic gearshift was already developed around 1925, but for decades the German car industry showed no interest; only at the beginning of the 1960s was the "automatic" based on the American model adopted. E. Dichter, Strategie im Reich der Wünsche, Munich 1964, 322ff.

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130 M. Domarus, (ed.), Hitler, Reden u. Proklamationen 1932-1945, Wiesbaden 1973, II, 576f.; Kraemer, Technokratie, 68; Blaich, Fehlrationalisierung, 32; Betz, Volksauto, 57f.; Wolf, Eisenbahn, 115f.; Vogt, 175; E. Merkert, Der Lastwagenverkehr seit dem Kriege, Berlin, 1926, 82ff, 104; Ritzau, Schatten, 99ff.; Der Spiegel, 23. 3. 1955, 12; L. Engelskirchen, Die Ge- schichte des Hochgeschwindigkeitsverkehrs, in: Gundler (ed.), Unterwegs und mobil, 147.

131 Produktivkräfte, III, 287/310f.; Betz, Automobilia, 169; Bolenz, Baubeamte, 65; F. Todt, Das Straßenbauprogramm A. Hitlers u. die deutschen Ingenieure, in: Deutsche Technik 1.1933, 53;
F. Todt, Fehlerquellen beim Bau von Landstraßendecken aus Teer u. Asphalt, Diss. München 1931, 10; T. Kunze and R. Stommer, Geschichte der Reichsautobahn, in: R. Stommer (ed.), Reichsautobahn. Pyramids of the Third Reich, Marburg 1982, 33.

132 Betz, Automobilia, 135f.; P. A. Rappaport, Die deutsche Straße, in: Deutsche Technik 2.1934, 653; Pflug, 267; Holzapfel, 74.

133 Hitler, Monologe, 192, 39, 125; Sombart, Zähmung, 29; against Sombart: H. Bornitz, in: Deut- sche Technik 3.1935, 70ff.; Todt, Fehlerquellen, 1; Lawaczek was an opponent of the railroad and a supporter of the promotion of road traffic: ders., Technik, 45f.; Ludwig, Technik
u. Engineers, 319ff.

134 Ludwig, ibid., 303; Hughes, Momentum, 372; Domarus (ed.), I, 208; Hitler, Monologe, 64, 398; Todt: Deutsche Technik 2.1934, 564.

135 Franz, Landtechnik, 8; Franke, Motorisierung, 61; Produktivkräfte, III, 269; the director of the Westfälisches Freilichtmuseum Detmold, Stefan Baumeier, dates the beginning of the "tractor era" in Westphalia to the late 1950s (Neue Westfälische 31.5. 1988).

136 Landesmuseum Mannheim, 103ff., 110; Franke, ibid., 28ff., 38; Herrmann, 222; Preuschen, 174ff.; D. Stutzer, Geschichte des Bauernstandes in Bayern, Munich 1988, 325.

137 K. Vormfelde, Ein neues Weltbild durch den Mähdrescher, in: Zs. des VDI 75.1931, 153ff.;

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Die westdeutsche Wirtschaft und ihre führenden Männer, NRW, I, Oberursel 1969, 90f.; Fränkisches Freilandmuseum, Göpel, 43, 129; J. Scheffler, in: G. Hammer u. a., Vahlhausen, Alltag in einem lippischen Dorf 1900-1950, Detmold 1987, 70ff. (74, statement of a

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Old farmers: "And the combine harvester made the farmer and his wife stand all alone on his farm.")

V. At the limits of mass production

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4 W. Rathjen, Luftverkehr u. Weltraumfahrt, in: Troitzsch u. Weber, 514.

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proportion of foreigners was particularly high in those industries (steel, textiles, construction) that were particularly affected by rationalization in the 1970s.

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and 1980s were affected by the structural crisis. It can therefore be assumed that the recruitment of "guest workers" partly helped to give these industries a breathing space, but also partly promoted strategies of rigid mass production. This is, with Japan as a counter-example, the thesis of Yong-Il Lee, Ausländerbeschäftung und technischer Fortschritt. The Recruitment Policy of the Federal Republic of Germany in Comparison with Japan's Closed Labor Market Policy (1955-1973), Diss. Bielefeld 2003.

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59 Waste incineration: Rodel, 73ff.; Marcard, Neuzeitliche Gesichtspunkte für den Bau von Müll- kraftwerken, in: AfW 4.1923, 161f., Radkau, Umweltfragen, 96f.; Genetic engineering: H. Harnisch, in: BDI, 35.

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61 F. Dessauer and K. A. Meißinger, Befreiung der Technik, Stuttgart 1931, 74; Radkau, Aufstieg, 334; E. Sänger, Raumfahrt - eine technische Überwindung des Krieges, Hamburg 1958; Eu- gen Sänger, the most prominent German rocket researcher of the time, attributed the founders of space travel the "rank of supermen" and compared the "mental resistance o f some sections of the population to space travel" with the "witchcraft beliefs of the Middle Ages": E. Sänger, Raumfahrt - eine technische Überwindung des Krieges, Hamburg 1958, Space travel, Düsseldorf 1963, 30, 35. Whereas he had just glorified space travel as the conqueror of war, he now (35f.) described the military rocket arsenal as a "witchcraft of the Middle Ages".
"technically the natural basis for practical space travel". - Even before 1914, aviation enthusiasts, as Bertha von Suttner complained, offered themselves to both the pacifists and the military and praised aviation as a peace and war technology as required: G. Brinker-Gabler, B. von Suttner, Frankfurt/M. 1982, 204f.

62 Bergmann, Rationalisierung, 66f.; L. Preller, Wandel der Arbeit heute, in: W. Bitter (ed.), Mensch u. Automation, Stuttgart 1966, 62 (warning reference to the experiences of the interwar period!); VDI-N. 48/1987, 26; Wurster, Computers, 275; S. Hilger, "Amerikanisierung" deutscher Unternehmen. Wettbewerbsstrategien und Unternehmenspolitik bei Henkel, Siemens und Daimler-Benz (1945/49-1975), Wiesbaden 2004, 244ff.

63 VDI-N. 26/1988, 2; Hartkopf and Bohne, 267, 301, 169; Vahrenholt; H. Zeller, Sicherheit aus der Sicht des Toxikologen, in: BASF, 145.

64 VDI-N. 15/1988, 30, 37/1988, 27; G. Lütge, in: Die Zeit, 27.2. 1987, 25; Kränzlein, 187f.; K. O. Henseling, Struktur u. Entwicklungsdynamik chemischer Risiken am Beispiel der Chlorchemie, in: WSI Mitt. 2/1988, 69ff.

65 Vahrenholt.

66 VDI-N. 38/1988, 33 (P. Kudlicza) 2/1989, 14 (Lersner); R. Dahrendorf, Themen, die keiner mehr nennt, in: Die Zeit 24.9. 1976, 9.

67 Holzapfel, 13; U. Kubisch, Aller Wehs Wagen, Berlin 1986, 113f.; Barthelu. Lingnau, 179, 323; VDI-N. 7/1988, 1, 4; Der *Spiegel* 28.11.1988, 115 and 6.2. 1989, 99 (Ford boss Goeudevert on "inbreeding engineering").

68 Hartkopf and Bohne, 253; T. Kluge and E. Schramm, Wassernöte. Umwelt- u. Sozialgeschichte des Trinkwassers, Aachen 1986, 208. Counter-front: Wey, 250. magnetic levitation train: E. Callenbach, Ökotopia, Berlin 1978, 14; R. R. Rossberg, Radlos in die Zukunft. Die Entwicklung neuer Bahnsysteme, Zurich 1983; "Der Spiegel" 11/1997, 54-71 ("Ganz, ganz schneller Brü- ter"); VDI-N. 37/1989, 3 ("Transrapid: Die Chancen für den

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schwinden - Wie ein Flugzeug im Landeanflug"); H.-L. Dienel, Konkurrenz und Kooperation von Verkehrssystemen, in: Gundler, Unterwegs und mobil, 113.

69 A. A. Ullmann and K. Zimmermann, Umweltpolitik u. Umweltschutzindustrie in der BRD, Berlin 1981, 252, 264; VDI-N. 43/1988, 45 (environmental protection technology as the predominant domain of large-scale industry); cf. also the connections between solar technology and space travel and also between superconductor and military research (VDI-N. 45/1988, 39)!

70 Holzapfel, 5 5; N. Pieper, "Wunderkind mit Weltschmerz", in: Die Zeit 11. n. 1988, 41; C. Amery, Bileams Esel. Conservative Essays, Munich 1991, 219. According to the Allensbach survey, between 1966 and 1981 the proportion of those for whom technology is "more of a blessing" fell from 72 to 30 percent, but the proportion of those who consider technology more of a curse only rose from 3 to 13 percent: M. von Klipstein u. B. Strümpel, Der Überdruß am Überfluß, Munich 1984, 183. Dies. (ed.), Gewandelte Werte - erstarrte Strukturen, Bonn 1985, 45: "Only those projects that can be summarized under the motto 'Bigger, Faster, Further' [...] found more opponents than supporters."

71 D. Staritz, Geschichte der DDR 1949-1985, Frankfurt/M. 1985, 233.

72 H. Schelsky, Die sozialen Folgen der Automatisierung, Düsseldorf 1957, 38.

73 "Die Zeit", December 22, 1989, 23/25.

74 "Der Spiegel", April 23, 1990, 178.

75 A prominent example is the GDR steel industry's reluctance to introduce the oxygen blowing (LD) process. As it was largely dependent on scrap due to a lack of domestic iron ore resources, it behaved rationally by sticking with the Siemens-Martin process for the time being. S. Unger, Technische Innovationen einer "alten Branche": Die Einführung der Sauerstofftechnologie in der Stahlindustrie der Bundesrepublik und der DDR, in: J. Bähr/D. Petzina (eds.), Innovationsverhalten und Entscheidungsstruk- turen, Berlin 1996, 49-78.

76 J. Radkau, Holz, Munich 2007, 144.

77 J. Radkau, Did the productive forces revolt against real existing socialism? Techno-historical notes on the collapse of the GDR, in: 1999 H. 4/90, 13-42.

78 G. Mittag, At any price. Im Spannungsfeld zweier Systeme, Weimar 1991, 242-251.

79 J. Kuczynski, Four Revolutions of the Productive Forces, Berlin 1975, 110; he, Zur Debatte über das Verhältnis von Technik und Fortschritt, in: Bll. für deutsche und internationale Politik 24 (1979), 349.

80 D. L. Augustine, Red Prometheus. Engineering and Dictatorship in East Germany 1945-1990, Cambridge, Mass. 2007, 128.

81 H.-L. Dienel, "Das wahre Wirtschaftswunder." Aircraft production, airlines and domestic air traffic in a West-East comparison 1955-1980, in: J. Bähr/J. Petzina (eds.), Innovationsverhalten und Entscheidungsstrukturen. Vergleichende Studien zur wirtschaftlichen Entwicklung im geteilten Deutschland 1945-1990, Berlin 1996, 349.

82 A. Steiner, From Plan to Plan. Eine Wirtschaftsgeschichte der DDR, Berlin 2007, 161f. Jörg Roesler to the author, 9.3.1993: Ulbricht had only publicly uttered this slogan originating from Khrushchev o n c e , in 1969; but this saying had been used against him again and again by the anti-Ulbricht front in the party leadership!

83 Mitt. by Verena Witte, who is doing her doctorate on this topic at the University of Bielefeld.

84 A grotesque overestimation of cybernetics was revealed by the GDR negotiator Werner Krause in August 1990 during the negotiations on reunification: "We engineers and computer scientists [...] know the control mechanisms of systems, we can analyze their c o n t r o l l a b i l i t y . " ("Der Spiegel", 13.8.1990, 27) It was the same arrogance t h a t the West German cyberneticist Karl Steinbuch expressed in 1968 with his book "Falsch programiert"!

85 Staritz, 105f.

86 M. Röcke, The Trabant, Königswinter 1990.

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87 P. Hübner/M. Rank, Schwarze Pumpe. Kohle und Energie für die DDR, Berlin 1988; "Die Welt" 13.2.1990, 14.
88 ZK der SED (ed.), Chemie gibt Brot - Wohlstand - Schönheit, Berlin 1958, 8.
89 R. S. Stokes, Constructing Socialism. Technology and Change in East Germany, 1945-1990, Baltimore 2000, 85.
90 A. S. Shevchenko, Der Mais. International experiences, Berlin 1960.
91 S. Merl, Entstalinisierung, Reformen und Wettlauf der Systeme, in: S. Plaggenberg (ed.), Handbuch der Geschichte Rußlands, Stuttgart 2002, 215ff.
92 M. Reichert, Kernenergiewirtschaft in der DDR. Entwicklungsbedingungen, konzeptioneller Anspruch und Realisierungsgrad, St. Katharinen 1999; see my foreword, VIIf.
93 Cf. Augustine, 130.
94 H.-L. Dienel, "Das wahre Wirtschaftswunder," 342.
95 Stokes, 125f.
96 J. Roesler et al, Wirtschaftswachstum in der DDR 1945-1970, Berlin 1986, 196.
97 D. Staritz, 158.
98 P. C. Ludz, Die DDR zwischen Ost und West. From 1961 to 1976, Munich 1977, 73ff.
99 G. Kosel, Unternehmen Wissenschaft. Memories, Berlin 1989.
100 Cf. W. Mühlfriedel/K. Wiessner, Die Geschichte der Industrie der DDR, Berlin 1989, 306.
101 A secret memo from the SED Politburo about a meeting in Moscow on 21. 8. 1970, in: P. Przybylski, Tatort Politbüro. Die Akte Honecker, Berlin 1991, 109f.
102 E. Krenz, When Walls Fall, Vienna 1990, 55.
103 Przybylski, 106.
104 Noon, 151f.
105 A. Steiner, From Plan to Plan. An Economic History of the GDR, Berlin 2007, 210f.
106 Oral communication from Matthias Greffrath.
107 In the alliterative chapter title by Stokes (p. 110), "The Software of Socialism", is "Software" essentially meant metaphorically!
108 K. H. Beckurts in: BDI (ed.), Industrieforschung, Cologne 1986, 99.
109 J. Roesler, Im Wettlauf mit Siemens: Die Entwicklung von numerischen Steuerungen für den DDR-Maschinenbau im deutsch-deutschen Vergleich, in: L. Baar/D. Petzina (eds.), Deutsch-deutsche Wirtschaft 1945 bis 1990. Strukturveränderungen, Innovationen und regionaler Wandel: Ein Vergleich, St. Katharinen 1999, 349-389: In the 1960s, the GDR even had a head start over the Federal Republic in NC machines; it was only with computer-controlled CNC machines, which, thanks to diversified software, achieved a flexibility previously unattained in a u t o m a t i o n and thus ideally met the needs of machine tool production, that the GDR fell hopelessly behind. Similarly, J. Roesler, Einholen wollen und Aufholen müssen. Zum Innovationsverlauf bei numerischen Steuerungen im Werkzeugmaschinenbau der DDR vor dem Hintergrund der bundesrepubli- kanischen Entwicklung, in: J. Kocka (ed.), Historische DDR-Forschung, Berlin 1993, 263- 285.
110 Augustine, 310.
111 E. Richert, Die DDR-Elite oder Unsere Partner von morgen? Reinbek 1968, 58ff.
112 Thus the emigrated GDR economist H. von Berg in "Der Spiegel" May 26, 1986, 161f.
113 S. Franke/R. Klump, Offset as a challenge for innovative action: Die Innovationsaktivitäten der Druckmaschinenhersteller König & Bauer AG (Würzburg) und VEB Planeta (Radebeul) in den sechziger Jahren, in: Bähr/Petzina, Innovationsverhalten (see above), 215-249.
114 Augustine, 132.
115 H.-L. Dienel, Die Linde AG. Geschichte eines Technologiekonzerns 1879-2004, Munich 2004, 366, emphasizes "cooperation with the competition" as a characteristic element in the tradition of this typically German company.

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116 J. Roesler, Industrieinnovation und Industriespionage in der DDR. Der Staatssicherheitsdienst in der Innovationsgeschichte der DDR, in: Zs. für das vereinigte Deutschland, 27. Jg., July 1994, 1026-1040.
117 C. Kleinschmidt, Technik und Wirtschaft im 19. und 20. Jh., 57.
118 Steiner, 209f.
119 J. Roesler to the author, 9. 11. 1993: Until then, the VEB had still functioned in part like private c o m p a n i e s .
120 Steiner, 234f.
121 J. Radkau, Max Weber, Munich 2005, 199.
122 Heinz Nixdorf Museumsforum, Museum Guide, Paderborn 2000, 134.
123 Federal Ministry for Inner-German Relations (ed.), DDR-Handbuch, 3rd ed. Vol. 2, Cologne 1985, 1526.
124 G. Barkleit, Mikroelektronik in der DDR, Dresden 2000, 41.
125 B. Plettner, Abenteuer Elektrotechnik. Siemens and the development of electrical engineering since 1945, Munich 1994, 138.
126 "Wirtschaftswoche", July 3, 1992, 34f.; "Der Spiegel", March 16, 1992, 140f. (Interview with H. von Pierer).
127 "Der Spiegel", March 23, 1992, 208f.
128 K. Seitz, The Japanese-American Challenge. Germany's high-tech industries fight for survival, 4th ed. Munich 1992.

Homo faber, homo ludens, homo sapiens - and the question of synergy

1 In the account of the semiconductor physicist Hans Queisser (Kristallene Krisen, Munich 1985), the history of microelectronics is primarily a history of semiconductors; in the Paderborn Nixdorf Museum Forum, on the other hand, semiconductor development is completely marginal and the main roots of the modern computer world are in office machines.
2 In the book written by two CERN employees, J. Gillies/R. Cailliau, Die Wiege des Web - Die spannende Geschichte des www, Heidelberg 2002, the genesis of the Internet is almost entirely a CERN story. In contrast, M. Bunz, Vom Speicher zum Verteiler - Die Ge- schichte des Internet, Berlin 2008, does not mention CERN at all! In M. W. Zehnder, Ge- schichte und Geschichten des Internets, Kilchberg 1998, 70, it is pure coincidence that the web originated at CERN.
3 G. Ostendorf, Die Geschichte der Vorhersagen im Bereich der Computertechnologie, Magister thesis, Bielefeld 1990.
4 K. Kempter, Heinz Nixdorf, Landsberg 2001, 159.
5 Heinz Nixdorf Museumsforum, Museum Guide, Paderborn 2000, 103, 133, 138.
6 E. Bonse, "A paradigm shift is not yet in sight", VDI-Nachrichten 35/1989, 16.
7 One successful Internet entrepreneur assured me, however, that she would never get involved with a partner who would engage in these games that lead to schizophrenia and delusions of grandeur!
8 Wilhelm Ostwald, the founder of electrochemistry and Nobel Prize winner in 1909, wrote in the same year: "While the telephone, for example, is a great energy saver for the busy businessman, the artist or scholar, especially in older years, rightly detests it." W. Ostwald, The Demand of the Day, Leipzig 1911, 62.
9 Heinz Nixdorf Museumsforum, Museum Guide, Paderborn 2000, 145.

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10 E. M. Rogers/J. K. Larsen, Silicon Valley Fever. An der Schwelle zur High-Tech-Zivilisation, Berlin 1985, 77. It is only much later (p. 162f.) that the reader learns that this belief is nonsense.

11 Thomas Gorsboth, based on many years of experience in various trade unions, repeatedly pointed out to me that not only screen work, but also warehouse and packaging work has increased enormously and that there is still *plenty of* backbreaking and assembly line work - only that these working environments lie in the shadow of public a t t e n t i o n !

12 Plattner's corporate philosophy and production orientation are very similar in their basic features to those of Nixdorf: company-specific software programs with a strong focus on special customer requirements and user-friendliness, combined with the traditional German corporate philosophy of retaining experienced employees even in times of crisis - at least this is what Hasso Plattner said in his speech at the SAP AG Annual General Meeting in Mannheim on May 9, 2003. SAP reached its limits when it was asked to develop a software program for the SPD party apparatus. A well-founded history of SAP is probably one of the greatest desiderata in the latest history of technology and business!

13 "Spiegel" 28/1999 78ff.

14 J. Huizinga, Homo ludens. Vom Ursprung der Kultur im Spiel, Reinbek 1987 (originally 1938); especially 215f.: "Spielmäßiges im modernen Geschäftsleben."

15 Among the great inventors still alive, Artur Fischer, who obtained over a thousand patents, acknowledged his playful drives: see his interview with Joseph Hoppe ("Spieltrieb und Erfindergeist") in S. Poser et al. (eds.), Spiel mit Technik. Catalog for the exhibition at the Deutsches Technikmuseum Berlin, Berlin 2006, 174ff.

16 Still in the multi-year project of the Berlin Social Science Center (WZB) on large technical systems, in which I was involved and the results of which were published in 1994 - I. Braun/B. Joerges (eds.), Technik ohne Grenzen - , the Internet was not a topic at all - no matter how hard we tried to keep up with the state of the art in systems technology at the time - and the discussion revolved almost exclusively around permanently networked and centrally controlled systems. Janet Abbate's seminal opus (Inventing the Internet, Cambridge/Mass. 1999) e m e r g e d from an associated dissertation in 1994: at a time when the Internet already existed technically, but not yet as a globally popular communication medium. This work, published in the "Inside Technology" series of the MIT (Massachusetts Institute for Technology), therefore treats the history of the Internet as an insider story within the military-industrial complex. From today's perspective, this is rather the p r e h i s t o r y of the Internet!

17 G. Mener, Between Laboratory and Market. Geschichte der Sonnenenergienutzung in Deutschland und den USA 1860-1986, Munich 2000; J. Weyer, Größendiskurse. Die strategische Insze- nierung des Wachstums sozio-technischer Systeme, in: I. Braun/B. Joerges (eds.), Technik ohne Grenzen, Frankfurt/M. 1994, 355f.

18 H. Keller: The all-purpose engineer. Anti-tank missiles or solar systems, fighter planes or sports machines: Ludwig Bölkow designed whenever a task appealed to him. In: "Die Zeit", April 15, 1994, 42.

19 Representative contemporary document: Ad-hoc Committee of the Federal Minister of Research and Technology (ed.), Solare Wasserstoffenergiewirtschaft. Expert opinion and scientific contributions, Bonn 1988.

20 J. Radkau, Wood. Wie ein Naturstoff Geschichte schreibt, Munich 2007, especially 150ff.

21 M. Giesecke, Der Buchdruck in der frühen Neuzeit. A historical case study on the implementation of new information and communication technologies, Frankfurt/M. 1991, 124-167.

22 W. Müller/B. Stoy, Decoupling. Economic growth without more energy? Stuttgart 1978.

23 E. M. Rogers/J. K. Larsen, Silicon Valley Fever, Berlin 1985, 203ff.

24 W. Ostwald, The demand of the day, 414.

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25 U. Kubisch/V. Janssen, Borgward. A look back at the economic miracle, everyday factory life and a car myth, Berlin 1986, 115.
26 The shift in the focus of Linde's refrigeration engineering from "large-scale refrigeration" to "Kleinkälte", where the Americans had initially been ahead of the Germans and Linde had hesitated, H.-L. Dienel, Die Linde AG, 220ff., 224ff.
27 "Der Spiegel". 2.5.1994, 91: "Consumer-friendly operating concepts fail again and again due to the technical infatuation of the staff in the development laboratories."
28 "Spiegel" 20/1996, 121.
29 L. Payer, Medicine & Culture. Varieties of Treatment in the United States, England, West Germany, and France, New York 1988, 78: "Perhaps because both fringe and high-tech medicines are accepted, West Germans are inclined to use all sorts of medicine to an extent that others would regard as excessive."
30 P. Borscheid, Das Tempo-Virus. A Cultural History of Acceleration, Frankfurt/M. 2004, 378.
31 J. Radkau, Das Zeitalter der Nervosität. Germany between Bismarck and Hitler, 2nd ed. Munich 2000, especially 155ff.
32 R. Knasmüller/T. Keul, Real New Economy. Über die geplatzten Träume und die wahre Chancen des digitalen Wirtschaftswunders, Munich 2002, 59f.
33 Similar observations for the French 68ers in the most important opus c r i t i c a l of capitalism of recent times: L. Boltanski/E. Chiapello, Der neue Geist des Kapitalismus, Konstanz 2003 (French first edition 1999).
34 E. Verg, Milestones, Leverkusen 1988, 197.
35 Peter Schirmbeck (ed.), "Morgen kommst Du nach Amerika." Memories of working at Opel 1917-1987, Berlin 1988, 96.
36 P. Glotz, Rod Sommer. Der Weg der Telekom, Hamburg 2001, 11.
37 Cf. the "Spiegel" title 23/2008 from June 2, 2008: "Big BroTher. The sinister state conglomerate".
38 G. Ogger, Rivets in pinstripes. Deutschlands Manager im Zwielicht, Munich 1992, 63.
39 In reality, the problem exists as it always has, and is even exacerbated by mergers and reorganizations. As Roland Springer points out: "The biggest time wasters in change processes are unresolved conflicts of objectives and interests between the respective divisions and departments." VDI-Nachrichten 39/2003, 2.
40 H. Schumann, Revolution des Kapitals, in: "Der Spiegel" 19.6.1999.
41 S. Hilger, "Americanization" of German companies, 53ff.
42 Ogger, 139ff.
43 Ogger, 37.
44 D. Schweer, Daimler Benz. Interior views of an empire, Düsseldorf 1995.
45 The review by former Hoechst board member Karl- Gerhard Seifert, Ein Stück deutscher Chemiegeschichte. Die Zerschlagung der Hoechst AG, in: CHEManager, March 28, 2008, especially the summary at 10: "Today, many people ask themselves: How could all this happen? The answer is very simple, even if many people don't like it: (almost) everyone was in favor of it" - from the shareholders to the trade union leaders, even up to the Hessian government at the time! In retrospect, Edzard Reuter also interpreted his own misguided strategy - despite all the s e l f - j u s t i f i c a t i o n - a s t h e result of a "Zeitströmung": "was it perhaps related to the pressure of the so-called shareholder-holder value mentality that was just beginning at that time - which in my judgment could become a deadly danger for our Western economic system?" In: Boch (ed.), History and Future of the German Automotive Industry, 275.
46 I owe this insight to Edda Müller (interview on March 22, 2006), who, as an environmental politician, has repeatedly experienced that even those entrepreneurs who profit from government environmental regulations are opposed to environmental regulations at relevant conferences.

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because in wide circles of the economy people automatically and reflexively take a defensive stance against "eco"!

47 "Financial Times Deutschland", March 3, 2006 (Wolfgang Münchau).

48 Susanne Hilger ("Amerikanisierung" deutscher Unternehmen, Wiesbaden 2004, 283) also gains the impression, on the basis of internal files, that Daimler-Benz had joined the "The trend to diversify into new technologies was demonstratively closed until the early 1980s": a situation that could be perceived as provocative by innovators!

49 F. Fukuyama, The Conflict of Civilizations, Munich 1995, 250.

50 J. Radkau, Max Weber, Munich 2005, 500ff. Werner Abelshauser in a discussion about his "Clash of Civilizations" on 18. 11. 2003: Schmoller, however, was a "master of institutional camouflage" and, following the historicist spirit of the times, had repackaged what were in fact new institutions as traditional guild institutions!

51 G. W. F. Hallgarten/J. Radkau, Deutsche Industrie und Politik von Bismarck bis in die Gegenwart, 2nd ed. Reinbek 1981, 446f.

52 Even Roland Springer, who for a time held a responsible position in the work organization of DaimlerChrysler and considers a return to limited Taylorism to be advantageous in the automotive industry (hes., Rückkehr zum Taylorismus? Arbeitspolitik in der Automobilindustrie am Scheideweg, Frankfurt/M. 1999), argues for a "co-management of works councils", especially in view of the fact that "in areas of non-automated, variant-rich series production", not only skilled workers are needed, but also an "increasing demand for unskilled and semi-skilled workers", who cannot be integrated into the corporate culture without works councils. In: VDI-Nachrichten 28/2002, 2.

53 P. Glotz, "Den Europäern fehlt der Wagemut", in: "Süddeutsche Zeitung", 11.6.2003, 2.

54 "Der Spiegel" 48/2007, 77f.

55 This is the blurb from T. Knipp, Der Deal. The story of the biggest takeover of all time, Hamburg 2007.

56 Ibid, 208, 226.

57 VDI-Nachrichten, 19.11.1999, 9, and 9.6.2000, 33 ("Operation successful, patient dead"). Five years later, Roland Tichy, editor-in-chief of the business magazine "Euro", summarized in the "Handelsblatt" (February 6, 2004): "For only 7,000 employees in the small mobile communications division, a group with 130,000 employees and world-leading technologies [...] was broken up, shareholder capital in the three-digit billion range was destroyed and competition in the mobile communications sector was weakened throughout Europe."

58 Knipp, The Deal, 228, 232f.

59 E. Verg et al, Meilensteine. 125 Jahre Bayer 1863-1988, Cologne 1988; E. Bäumler, Die Rotfabri- ker. Familiengeschichte eines Weltunternehmens, Munich 1988; K. Tenfelde et al. (eds.), Stimmt die Chemie? Co-determination and social policy in the history of the Bayer G r o u p , Essen 2007, 242f., 417-420.

60 A particular curiosity: Dormann cited the critical ecological perspective on his company when disregarding the Hoechst tradition: "When people heard 'Hoechst', they only thought of chemical accidents anyway." "Handelsblatt", July 21, 2007 ("The Red Factory").

61 "Even the life science concept is considered outdated", noted the "Handelsblatt" on November 10, 2003 ("Change in large-scale chemistry continues - companies lose former strength"). The Monsanto Group, which not only dominates the business with genetically modified seeds, but also produced the defoliant Agent Orange during the Vietnam War, is regarded as the world market leader in industrial "life science".

62 K.-G. Seifert, A piece of German chemical history. The break-up of Hoechst AG, in: CHEManager, March 28, 2008, 14.

63 "Handelsblatt", April 27, 2004, 10 ("The bitter taste of the takeover"). As recently as July 22, 2000, an article in the "Süddeutsche Zeitung" celebrated the Aventis Group created by the merger as the incarnation of a supranational future: "And which nation does Aventis belong

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Aventis, for example, merged from Farbwerke Hoechst, until recently a flowering of the German chemical industry, and the no less proud Rhone-Poulenc: France or Germany?"

64 "Der Spiegel" 50/1997, 122ff.; 49/1998, 98; oral comm. by Theo Tekaat, August 15, 2006.

65 "Cicero", Dec. 2004 ("I earn three million").

66 R. Tichy: "Please help yourself! Only Germany has de facto anticipated the EU Takeover Directive in anticipatory obedience", in: "Handelsblatt" 26/2004 (6.2.04), 9.

67 Cf. "Süddeutsche Zeitung", March 20, 1999, 25: "The chemical industry in its element: Companies a r e making record profits in the billions and still moaning about the difficult year 1999."

68 Is BASF an exceptional case? Cf. in contrast "Financial Times Deutschland", July 14, 2003: "BASF puts its (sic!) stamp on the industry." However, "Handelsblatt", October 25, 1999, 22: "In contrast to the Ludwigshafen BASF Group, Hoechst lacked the large 'backward integrated' Verbund sites. Petrochemical starting materials such as ethylene and propylene, which are firmly integrated into the value chain at BASF, always had to be sourced externally by the Frankfurt-based group." However, u n l i k e B A S F , Hoechst had a long tradition in pharmaceutical production.

69 W. Abelshauser (ed.), Die BASF. Eine Unternehmensgeschichte, Munich 2002, 631ff.; on the Verbund system as a "technological paradigm" also 493.

70 R. Wizinger, Chemische Plaudereien, Bonn 1934, 127, 5.

71 K.-G. Seifert, A piece of German chemical history, 14.

72 Radkau, Max Weber, 270.

73 M. Seefelder, Opium. Eine Kulturgeschichte, Munich 1990, 210.

74 "Handelsblatt", December 12, 2005, 16 ("Ascent and descent under the Bayer cross").

75 "Handelsblatt", July 21, 2006, 10 ("The Red Factory").

76 W. Abelshauser, Die BASF, 612f.

77 Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (ed.), GreenTech made in Germany. Environmental Technology Atlas for Germany, Munich 2007, 9.

78 H.-Y. Park, Das Duale System der Berufsausbildung in der deutschen Nachkriegszeit zwischen Restauration und Reform, Diss. Bielefeld 2002.

79 Ibid, 41.

80 Ibid, 16.

81 L. Engelskirchen, Die Geschichte des Hochgeschwindigkeitsverkehrs, in: B. Gundler et al. (eds.), Unterwegs und mobil. Verkehrswelten im Museum (Deutsches Museum), Frankfurt/M. 2005, 151.

82 Cf. also Christopher Kopper on the electrification of the Bundesbahn: "The environmental friendliness of the railroads was merely the side effect of an investment policy that followed completely different paradigms in the 1950s and 1960s." In: F.-J. Brüggemeier/J. I. Engels (eds.), Nature and Environmental Protection after 1945, Frankfurt/M. 2005, 324.

83 A treasure trove of such erroneous predictions is T. Forester, Die High-Tech-Gesellschaft. Dreißig Jahre digitale Revolution, Stuttgart 1990, and J. Radkau, "Tastenlose Computer, papierloses Büro. Not all high-tech dreams have come true." FAZ 12. 12. 1990, 12.

84 The astute study by IBM works council chairman Wil- fried Glißmann and philosopher Klaus Peters is groundbreaking here: Mehr Druck durch mehr Freiheit. Die neue Autonomie in der Arbeit und ihre paradoxen Folgen, Hamburg 2001; ibid. 28: In modern companies, the ambition is to "reproduce the performance dynamics of a self-employed person among those who are not self-employed and to make it the main engine for increasing a company's productivity". In other words, a kind of rediscovery of the "productive power of man" - with similar socio-political ambivalence as Taylorism! Heiner Minssen, Arbeits- und Industriesoziologie. Eine Einführung, Frankfurt/M. 2006: "private organiza-

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tion and communication tools such as appointment planners, cell phones and laptops are becoming i n d i s p e n s a b l e , the boundaries between work and life are becoming blurred." Recent industrial sociology has otherwise paid little attention to the technology factor.

85 Oral communication from Klaus Lang, Labor Director of Georgsmarienhütte Holding GmbH, May 30, 2008.

86 Significantly, among the top entries in the Körber Foundation's 1977 German history competition for schoolchildren, "The changing world of work and technology" - still a treasure trove on this subject today - the only entry that deals with the switch to electronics is about printing technology (the 53rd entry by Martin Forster from Syke, 280 pages long).

87 A. Klönne et al, Freiheit, Wohlstand, Bildung für alle! Vom Ortsverein Bielefeld des Deutschen Buchdruckerverbandes zur Vereinten Dienstleistungsgewerkschaft ver.di, Hamburg 2004, 141. Tenfelde, Stimmt die Chemie? 341f.; Der *Spiegel* 36/1982, 85.

88 VDI News 42/2003, 3.

89 L. Marschall, In the Shadow of Chemical Synthesis. Industrial Biotechnology in G e r m a n y (1900-1970), Frankfurt/M. 2000.

90 "Die Zeit" March 20, 1992, 33 (H. Blüthmann/F. Vorholz: "We are further ahead than the Japanese")

91 K. Möser, Geschichte des Autos, Frankfurt/M. 2002, 287.

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